A multi-directional exploration of the relationship between sleep, appetite and exercise within middle-aged men

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B. Exercise Science (Honours Class 1)

This thesis is submitted as a requirement for the Doctor of Philosophy

School of Exercise Science, Sport & Health
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Certificate of Authorship

I, Penelope Larsen,

“I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma at Charles Sturt University or any other educational institution, except where due acknowledgement is made in the thesis: *The interrelationship of sleep, appetite and exercise: a wakeup call for the middle-aged man*. Any contribution made to the research by colleagues with whom I have worked with at Charles Sturt University or elsewhere during my candidature is fully acknowledged. I agree that this thesis be accessible for the purpose of study and research in accordance with the normal conditions established by the Executive Director, Library Services or nominee, for the care, loan and reproduction of theses.”

Signature:  
Date: 28/03/2019

*Subject to confidentiality provisions as approved by the University*
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To everyone, thank you!
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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>1RM</td>
<td>One repetition maximum</td>
</tr>
<tr>
<td>α-MSH</td>
<td>Alpha-melanocyte-stimulating hormone</td>
</tr>
<tr>
<td>AASM</td>
<td>American Academy of Sleep Medicine</td>
</tr>
<tr>
<td>AFT</td>
<td>Afternoon exercise</td>
</tr>
<tr>
<td>AgRP</td>
<td>Agouti-related peptide</td>
</tr>
<tr>
<td>AHI</td>
<td>Apnoea-Hypopnea Index</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
</tr>
<tr>
<td>ANS</td>
<td>Autonomic nervous system</td>
</tr>
<tr>
<td>ATP</td>
<td>Adenosine triphosphate</td>
</tr>
<tr>
<td>AUC</td>
<td>Area under the curve</td>
</tr>
<tr>
<td>BASE</td>
<td>Baseline</td>
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<td>BMI</td>
<td>Body mass index</td>
</tr>
<tr>
<td>BP</td>
<td>Blood pressure</td>
</tr>
<tr>
<td>CART</td>
<td>Cocaine- and amphetamine-related transcript</td>
</tr>
<tr>
<td>CHO</td>
<td>Carbohydrates</td>
</tr>
<tr>
<td>CNS</td>
<td>Central nervous system</td>
</tr>
<tr>
<td>CONT</td>
<td>Control</td>
</tr>
<tr>
<td>CP</td>
<td>Creatine phosphate</td>
</tr>
<tr>
<td>CWI</td>
<td>Cold water immersion</td>
</tr>
<tr>
<td>DEP</td>
<td>Deprivation</td>
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<tr>
<td>ECG</td>
<td>Electrocardiography</td>
</tr>
<tr>
<td>EEG</td>
<td>Electroencephalography</td>
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<td>Energy intake</td>
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<td>Electrooculography</td>
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<td>Epworth Sleepiness Scale</td>
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<td>EVEN</td>
<td>Evening exercise</td>
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<td>Sleep extension</td>
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<td>Food Cravings Questionnaire</td>
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<td>FRAG</td>
<td>Sleep fragmentation</td>
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<tr>
<td>GH</td>
<td>Growth hormone</td>
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<td>GLP-1</td>
<td>Glucagon-like peptide-1</td>
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<td>GLUT 4</td>
<td>Glucose transporter</td>
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<tr>
<td>HIE</td>
<td>High-intensity exercise</td>
</tr>
<tr>
<td>HIIE</td>
<td>High-intensity interval exercise</td>
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<td>HPA</td>
<td>Hypothalamic-pituitary-adrenal</td>
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<tr>
<td>HR</td>
<td>Heart rate</td>
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<tr>
<td>ICC</td>
<td>Interclass correlation</td>
</tr>
<tr>
<td>LIE</td>
<td>Low intensity exercise</td>
</tr>
<tr>
<td>MAP</td>
<td>Maximal intensity attained</td>
</tr>
<tr>
<td>MET</td>
<td>Metabolic equivalent</td>
</tr>
<tr>
<td>MICE</td>
<td>Moderate-intensity continuous exercise</td>
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<td>Morning exercise</td>
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<td>N1</td>
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<tr>
<td>NPY</td>
<td>Neuropeptide Y</td>
</tr>
<tr>
<td>NREM</td>
<td>Non-rapid eye movement</td>
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<tr>
<td>NSD</td>
<td>No significant difference</td>
</tr>
<tr>
<td>OFC</td>
<td>Orbitofrontal cortex</td>
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<tr>
<td>OSA</td>
<td>Obstructive sleep apnoea</td>
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<tr>
<td>PA</td>
<td>Physical activity</td>
</tr>
<tr>
<td>PCA</td>
<td>Principal components of analysis</td>
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<td>PO</td>
<td>Power output</td>
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<tr>
<td>POMC</td>
<td>Proopiomelanocortin</td>
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<tr>
<td>POMS</td>
<td>Profile of Mood States</td>
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<td>Description</td>
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<td>--------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>PRE</td>
<td>Prior to exercise</td>
</tr>
<tr>
<td>PRO</td>
<td>Proteins</td>
</tr>
<tr>
<td>PSQI</td>
<td>Pittsburgh Sleep Quality Index</td>
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<td>Polysomnography</td>
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<tr>
<td>PSS</td>
<td>Perceived Stress Scale</td>
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<tr>
<td>PYY&lt;sub&gt;total&lt;/sub&gt;</td>
<td>Peptide tyrosine tyrosine</td>
</tr>
<tr>
<td>REC</td>
<td>Sleep recovery</td>
</tr>
<tr>
<td>REI</td>
<td>Relative energy intake</td>
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<tr>
<td>REM</td>
<td>Rapid eye movement</td>
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<td>RES</td>
<td>Sleep restriction</td>
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<tr>
<td>REX</td>
<td>Relaxation</td>
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<td>RPE</td>
<td>Rating of Perceived Exertion</td>
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<td>SCN</td>
<td>Suprachiasmatic nucleus</td>
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<td>SD</td>
<td>Standard deviation</td>
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<td>SE</td>
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<td>Sleep manipulation</td>
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<td>Sleep quality</td>
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<td>Slow wave sleep</td>
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<td>Three Factor Eating Questionnaire</td>
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<td>TMD</td>
<td>Total mood disturbance</td>
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<td>TSD</td>
<td>Total sleep deprivation</td>
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<td>Total sleep time</td>
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<td>VAS</td>
<td>Visual Analogue Scale</td>
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<td>VIG</td>
<td>Vigilance</td>
</tr>
<tr>
<td>VT</td>
<td>Ventilatory threshold</td>
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<tr>
<td>WASO</td>
<td>Wake after sleep onset</td>
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<tr>
<td>WB</td>
<td>Whole body</td>
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<tr>
<td>WD</td>
<td>Whole-day</td>
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<td>WHR</td>
<td>Waist-to-hip ratio</td>
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### List of Symbols and Units

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<td>$\alpha$</td>
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<tr>
<td>=</td>
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<tr>
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<td>kcal</td>
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<td>cm</td>
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<tr>
<td>$r$</td>
<td>Correlation coefficient</td>
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<td>Delta change</td>
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<td>≥</td>
<td>Greater than or equal to</td>
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<td>Hertz</td>
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<tr>
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<td>$\mu$U·mL$^{-1}$</td>
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<td>mL·min$^{-1}$</td>
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<td>mL·kg$^{-1}$·min$^{-1}$</td>
<td>Millilitres per kilogram per minute</td>
</tr>
<tr>
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<td>mmHg</td>
<td>Millimetres of Mercury</td>
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<td>x</td>
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</tr>
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<td>%</td>
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<tr>
<td>pg·mL$^{-1}$</td>
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<td>±</td>
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<td>rpm</td>
<td>Repetitions per minute</td>
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<td>Seconds</td>
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<td>VO$_{2\text{max}}$</td>
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Abstract
Sleep, eating habits and exercise are three key modifiable lifestyle behaviours that have been examined extensively independent of one another, or the relationship between two domains. However, closer examination of these behaviours collectively suggest synergistic physiological and psychological processes that interact in a complex, multi-directional fashion. Furthermore, evidence exists suggesting that middle-aged men do not currently meet minimum guidelines for sleep, diet or exercise. Therefore, the examination of the physiological and psychological implications these negative behaviours have on this population group warrant exploration. Hence, the aims of the current thesis were to: i) identify relationships between sleep, appetite and exercise, ii) examine prolonged (three consecutive days) sleep manipulation on appetite-related hormones, perceived appetite and mood states, iii) examine the effects of short-duration, vigorous exercise on appetite and mood states following sleep curtailment and extension, and iv) investigate the acute sleep and appetite responses to exercise intensity and exercise time-of-day in inactive middle-aged (35 - 60 y) men.

The first study (Chapter Three) of this thesis investigated the effects of prolonged sleep manipulation on appetite-related hormones, perceived appetite and mood states in inactive, middle-aged men. This study also aimed to examine whether self-paced vigorous exercise effects upregulated appetite and mood states associated with sleep curtailment (i.e. restriction and fragmentation). Nine men undertook four separate trials in a randomised fashion, which involved three consecutive nights of normal sleep (CONT: 6.5 - 8.5 h), sleep restriction (RES: 4 h), sleep fragmentation (FRAG: 6.5 - 8.5 h with intermittent alarms) or sleep extension (EXT: 10 h). Appetite-related hormones [ghrelin, leptin and total peptide tyrosine tyrosine (PYYtotal)], glucose, perceived appetite (hunger, fullness, desire to eat and prospective food consumption), food cravings (Food Cravings Questionnaire - state: FCQ-S) and mood states (POMS) were assessed after sleep manipulation and after exercise. For the exercise
protocol, participants were required to complete a 20 min self-paced cycling bout clamped at a rating of perceived exertion (RPE) of 15 (hard, vigorous). After sleep manipulation and exercise, PYY_{total} was lower for RES compared to EXT and FRAG (p ≤ 0.03). Also, following exercise, acylated ghrelin was higher for RES and EXT compared to CONT and FRAG (p ≤ 0.03); however, there were no between-trial differences for leptin (p > 0.05). Desire to eat and prospective food consumption were higher for RES compared to FRAG after sleep manipulation and exercise (p = 0.05). While, desire for sweet foods was higher for RES compared to CONT following sleep manipulation (p = 0.04); however, this difference was no longer present after exercise. Fatigue was higher for RES compared to all other trials after sleep manipulation (p ≤ 0.02); while perceived sleep quality was higher for CONT and RES compared to EXT and FRAG (p = 0.01 - 0.05). Interestingly, stress was higher for EXT compared to RES and CONT (p ≤ 0.02), indicating that for middle-aged adults, increasing sleep duration may not be beneficial but rather improving sleep continuity (e.g. reduce number of awakenings). Lastly, after sleep manipulation, TMD was higher for RES and FRAG compared to CONT and EXT (p ≤ 0.05); however, after exercise, mood results revealed that only fatigue remained higher for RES compared to all other trials (p ≤ 0.05). Collectively, these results suggest that while sleep curtailment may induce detrimental hormone and perceptual appetite and mood responses; short-duration, vigorous-intensity exercise may transiently attenuate these outcomes.

Study Two (Chapter Four) investigated the effects of high-intensity interval exercise (HIIE) and moderate-intensity continuous exercise (MICE) on sleep characteristics, appetite-related hormones, perceived appetite and free-living energy intake in inactive, middle-aged men. For this study, 11 overweight men (49 ± 5 y, BMI: 28 ± 3 kg·m²) completed two consecutive nights of sleep assessments to determine baseline (BASE) sleep stages and arousals recorded by polysomnography (PSG). Two trials were randomly assigned on separate afternoons (1400 - 1600 h), which included a 30 min exercise bout of either i) MICE (60 % VO_2peak) or ii) HIIE (60 s work at 100 % VO_2peak; 240 s rest at 50 %
VO_{2peak}). Measures included appetite-related hormones (acylated ghrelin, leptin, PYY_{total}) and glucose before exercise, 30 min after exercise and the morning after exercise; PSG recorded sleep following exercise; and actigraphy, and self-recorded sleep and food diaries up to 48 h after exercise. Results indicated that there were no between-trial differences for time in bed (TIB: p = 0.19) or TST (p = 0.99). Although, after HIIE, there was a greater proportion of stage N3 sleep (HIIE: 21 ± 7 %, BASE: 18 ± 7 %, p = 0.02) and the number of arousals during rapid eye movement (REM) sleep (HIIE: 7 ± 5, BASE: 11 ± 7, p = 0.05) were lower compared to BASE. The sleep results also indicated that wake after sleep onset (WASO) for MICE (41 ± 22 min) was lower compared to BASE (56 ± 33 min, p = 0.02). Acylated ghrelin was lower and glucose was higher 30 min after exercise for HIIE compared to MICE (p ≤ 0.05) suggesting favourable reductions in perceived hunger and energy intake. However, there were no significant differences for perceived hunger or fullness, nor did free-living energy intake decrease during the 48 h after exercise. As such, it appears that HIIE is more beneficial than MICE for improving some sleep variables and inducing transient changes in appetite-related hormones in inactive, middle-aged men; however, perceived appetite and energy intake may not be sensitive enough to these acute physiological changes.

The final study (Chapter Five) examined the effects of HIIE time-of-day on sleep characteristics, appetite-related hormones, perceived appetite and free-living energy intake. Initially, participants were required to undertake two consecutive nights of PSG sleep assessments to exclude sleep disorders and obtain BASE sleep characteristics. Following BASE, 11 overweight men (49 ± 5 y, BMI: 28 ± 3 kg·m²) completed three separate trials involving 30 min of HIIE (60 s work at 100 % VO_{2peak}: 240 s rest at 50 % VO_{2peak}) in the i) morning (MORN: 0600 - 0700 h), ii) afternoon (AFT: 1400 - 1600 h), and iii) early evening (EVEN: 1900 - 2000 h). Appetite-related hormones (acylated ghrelin, leptin and PYY_{total}) and glucose were measured before exercise, 30 min after exercise and the morning after exercise. Further, overnight PSG recorded sleep was measured the night following exercise; while
actigraphy, self-reported sleep and food diaries were recorded for 48 h after exercise. Like Chapter Four, there were no between-trial differences for TIB (p = 0.10) or TST (p = 0.46). Whole-night sleep data indicated greater proportion of stage N3 sleep was recorded for MORN (23 ± 7 %) compared to BASE (18 ± 7 %; p = 0.02). However, during the initial 180 min of sleep data, REM sleep (EVEN: 8 ± 5 %, BASE: 13 ± 5 %) was lower and non-REM (NREM) sleep was higher for EVEN (92 ± 5 %) compared to BASE (87 ± 5 %, p ≤ 0.05). Acylated ghrelin was higher 30 min after exercise for AFT compared to MORN and EVEN (p = 0.01); whereas glucose was higher for MORN compared to AFT and EVEN (p ≤ 0.02). There were no significant between-trial differences for leptin and PYY_total, perceived appetite or free-living energy intake despite significant reductions in acylated ghrelin, particularly for AFT and EVEN. Nonetheless, these findings show that HIIE can be performed safely in the early evening without subsequent sleep disruptions or detrimental perceived appetite or energy intake responses.

Collectively, these studies show that inactive, middle-aged men are vulnerable to detrimental health outcomes related to negative sleep, appetite, exercise and mood behaviours. Simultaneous examination of sleep, appetite and mood revealed that insufficient sleep, and increased negative moods and stress likely result in an upregulated drive for calorie-dense food intake, while vigorous intensity exercise may transiently alleviate these detrimental effects. Further, higher exercise intensities may be required to improve some subsequent sleep and appetite-related hormone responses. However, perceived appetite and free-living energy intake may not be sensitive enough to these acute signals. Nevertheless, HIIE may be performed at any time of day without inducing subsequent detrimental effects on sleep and appetite among middle-aged, inactive men. Thus, eliminating commonly cited exercise barriers and encouraging habitual exercise that may induce improvements in greater sleep, appetite and mood behaviours overtime and reduce the risk of detrimental health outcomes.
Chapter One: Introduction
1.1 Overview

The respective relationships between sleep, appetite and exercise have been explored extensively in isolation. However, on closer examination there are many synergistic physiological and psychological processes which suggest that these three key domains interact in a complex, multi-directional fashion (Keating, Johnson, Mielke, & Coombes, 2017; Kredlow et al., 2015). Based on experimental findings, experts have developed age-dependent guidelines for each of these domains with recommendations for adults including (1) obtain 7 - 9 h of sleep each night (Hirshkowitz et al., 2015); (2) eat a variety of nutritious foods from vegetable, fruit, grain, meat and dairy products that equate to 45 - 65 % carbohydrate, 20 - 35 % fat, and 15 - 25 % protein for total daily energy intake (NHMRC, 2013); and (3) be active on most, if not all days of the week, accumulating 150 - 300 min of moderate-intensity exercise or 75 - 150 min of vigorous-intensity exercise per week, and perform strength activities on two or more days per week (Department of Health, 2017). Moreover, deviations from these recommendations often lead to increased risk of comorbidities (type II diabetes mellitus) (Kredlow et al., 2015; Sharma & Kavuru, 2010) and detrimental psychological outcomes (increased stress and fatigue) (Gibson, 2006; Kahn et al., 2014).

Despite clear promotion of these recommendations, over the past several decades a proportion of adults have not been engaging in behaviours that align with minimum standards (Alexandratos & Bruinsma, 2012; ABS, 2015; Chaput et al., 2009). Instead, Chaput et al. (2009) reported that sleep duration for American adults (30 - 64 y) declined from 8.0 - 8.9 h sleep per night in 1960 to < 7.0 h sleep per night by 1995, and in 2009 at least 30 % of adults were obtaining < 6.0 h sleep per night. Likewise, a 2016 Australian sleep survey revealed a 5 - 10 % increase in reported sleep-related problems, such as reduced sleep duration due to work demands and increased daytime drowsiness, among participating adults (Adams et al., 2017) compared to results from a 2010 survey which indicated that 20 - 35 % of adults demonstrated
frequent sleep difficulties and daytime fatigue (Hillman & Lack, 2013). Further, survey analysis by Roenneberg et al. (2012) revealed a reduction in sleep duration of approximately 37 min on workdays within the previous decade which is associated with higher body mass index (BMI) for men but not women (Beccuti & Pannain, 2011). Similar to sleep data, eating patterns and behaviours have changed over the decades, the most notable changes being an increased availability of highly palatable, processed food (Austin, Ogden, & Hill, 2011; Kac & Pérez-Escamilla, 2013; Kearney, 2010; Monteiro, 2009) coinciding with a mean global rise in energy intake of approximately 500 kcal per person per day from 1961 - 2007 (Alexandratos & Bruinsma, 2012). For Australia alone, 20 % of the 45 % carbohydrate intake is from total sugars and 12 % of the 31 % fat intake is consumed in the form of saturated fats (ABS, 2014). Conversely, exercise engagement has remained relatively stable in Australia from 2011 - 2018, whereby 53 - 56 % of adults (18 - 64 y) met the 150 min minimum threshold for weekly exercise (ABS, 2013, 2015, 2018). However, the data did indicate that inactivity peaks at 35 y for those not meeting the physical activity guidelines (ABS, 2013, 2015, 2018), which coincides with age-related reductions in sleep duration (Alves et al., 2011; Dishman et al., 2015). There are likely many factors contributing to these trends in middle-aged adults with several studies revealing that this population appear to be time restrained due to longer working hours, carrying out domestic responsibilities and engaging in more sedentary behaviours, such as watching television or using a computer (Geiker et al., 2018; Gibala, Little, MacDonald, & Hawley, 2012; Rajaratnam & Arendt, 2001). There are findings which present poor health and wellbeing responses to sleep curtailment, calorie-dense diets, and minimal exercise participation independently (Brondel et al., 2010; Oliver et al., 2009; Spiegel et al., 2004b); however, the combination of negative behaviours associated with these key modifiable factors are yet to be examined concurrently.
Chapter 1: Introduction

Interactions between Sleep, Appetite and Exercise

Considerable literature supports the respective relationships between sleep and appetite (Copinschi et al., 2014; Simon et al., 1998; Spiegel et al., 2004b); sleep and exercise (Brand et al., 2014; Kredlow et al., 2015; Youngstedt, 2005); and appetite and exercise (Broom et al., 2017; Sim et al., 2014; Thivel et al., 2012). Insufficient sleep, as experienced by many middle-aged adults, is associated with increased activation of orexigenic signals which stimulate an increase in perceived appetite and cravings for calories-dense foods, as well as energy intake (Adams et al., 2017; Nedeltcheva et al., 2009; Spiegel et al., 2004b). Under chronic conditions, appetite perturbations associated with sleep loss tend to lead to more severe health conditions, such as obesity and type II diabetes mellitus, particularly for men (Barone & Menna-Barreto, 2011; Beccuti & Pannain, 2011; Imaizumi et al., 2015). Conversely, exercise has been shown to induce small improvements in total sleep time (TST) and stage N3 sleep (Kredlow et al., 2015). Yet, evening high-intensity exercise (HIE) is discouraged due to potential disruptions in sleep onset and continuity (AASM, 2001), despite more recent experimental evidence contradicting this notion (Stutz et al. 2019). In reference to the effects of exercise on appetite, the literature suggests that higher intensities induce greater declines in orexigenic signals resulting in extended reductions in perceived appetite and energy intake (Broom et al., 2017; Sim et al., 2014; Thivel et al., 2012). However, the effects of exercise time-of-day on appetite-related hormones, perceived appetite and energy intake remains largely unexplored (Bilski et al., 2016). Furthermore, the multi-directional relationship between sleep, appetite and exercise has not been explored simultaneously; thus, warrants further investigation given the many synergistic physiological and psychological outcomes that occur from the interactions of these three domains (Keating et al., 2017; Kredlow et al., 2015).
Therefore, as shown in Figure 1.1, this thesis will concurrently examine sleep, appetite and exercise within a middle-aged male population to explore the interrelationships of these primary factors under normal living conditions; examine the effects of prolonged sleep manipulation on appetite-related hormones and perceived appetite, while assessing short-duration, vigorous exercise as a possible mitigator of likely detrimental appetite responses to insufficient sleep; and investigating exercise intensity and time-of-day on sleep and appetite responses concurrently, given that changes in sleep (induced by exercise) likely affect appetite-related hormones and associated behaviours (Nedeltcheva et al., 2009; Spiegel et al., 2004b).
Figure 1.1 Schematic of thesis aims examining the multi-directional relationship between sleep, appetite and exercise. Each thesis aim is represented as aim one (1), aim two (2), aim three (3) and aim four (4).
1.2 The effect of sleep on appetite regulation and mood

Neurological and physiological processes unique to sleep, are carried out for the purpose of restoration and continued development (Paterson, 2012). For example, following intense learning, REM sleep tends to increase to stimulate ponto-geniculo-occipital waves, which directly correlate with task retention (Datta, 2000; Poe et al. 2010). Moreover, sleep modulates hormonal levels and glucose regulation to ensure prolonged fasting does not impair metabolic and endocrine pathways (Leproult & Van Cauter, 2010). Therefore, when sleep duration is reduced or sleep continuity is disrupted, a myriad of physiological and psychological alterations tend to occur, including acute upregulation of orexigenic signals (e.g. increased acylated ghrelin and decreased leptin) (Spiegel et al., 2004a; Spiegel et al., 2004b), heightened negative mood and emotional states (e.g. stress and anxiety) (Banks & Dinges, 2007), and increased feelings of fatigue and sleepiness (Ferrara & De Gennaro, 2001; Kahn, Sheppes, & Sadeh, 2013). Acute responses may further contribute to chronic overconsumption of energy-dense foods (Chaput, 2014), increased fat mass and poor weight management (Leproult & Van Cauter, 2010; Touitou et al., 2017), reduced glucose tolerance and insulin sensitivity (Sharma & Kavuru, 2010; Trenell, Marshall, & Rogers, 2007), and increased risk of disease onset (e.g. type II diabetes mellitus: T2DM and heart disease) (Knutson, Spiegel, Penev, & Van Cauter, 2007; Sharma & Kavuru, 2010).

Early evidence has suggested that sleep loss alters appetite-related hormone profiles, such as elevated acylated ghrelin levels and decreased circulating levels of leptin (Spiegel et al., 2004b; Taheri et al., 2004). These changes have been further associated with increased feelings of hunger and cravings for calorie-dense foods (Spiegel et al., 2004b), which results in excess energy intake (Brondel et al., 2010; Nedeltcheva et al., 2009). For instance, Spiegel et al. (2004b) reported an 18 % reduction in leptin and 28 % rise in ghrelin following two consecutive nights of 4 h sleep restriction (RES) compared to 10 h sleep extension (EXT). In addition to hormone changes, perceived hunger was 24 % higher, overall
appetite increased by 23 %, and desire for calorie-dense carbohydrate foods was 33 - 45 % higher for the RES trial (Spiegel et al., 2004b). Nedeltcheva et al. (2009) and Brondel et al. (2010) have both further supported these observations with reports of increased calorie intake following RES, particularly from snacks and a higher fat intake. Nevertheless, a recent review from Zhu et al. (2019) did not observe a significant impact of sleep restriction on mean leptin or ghrelin levels when the findings of 16 studies were considered. As such, it is possible that changes in the concentration of other appetite-related peptides may contribute or have a more substantial influence on perceived appetite and energy intake during sleep restriction, compared to leptin and ghrelin. Compared to RES, the effects of sleep fragmentation (FRAG) on appetite have been somewhat under explored. Although, Gonnissen et al. (2013) did observe a reduction in perceived fullness and increased desire to eat following one night of FRAG compared to a control (CONT) trial (normal sleep), despite no significant between-trial differences for ghrelin, leptin or glucose. Together, these studies suggest that both changes in sleep duration and wake after sleep onset (WASO) affect perceived appetite and eating behaviour while indicating that there are other factors, besides hormone changes, which likely contribute to the changes when sleep deprived.

In addition to appetite, insufficient sleep (both RES and FRAG) has also been linked to increases in mood disturbance, such as increased fatigue, depression and confusion, and reduced feelings of vigour (Finan, Quartana, & Smith, 2015; Kahn et al., 2014; Lentz, Landis, Rothermel, & Shaver, 1999). Kahn et al. (2014) demonstrated that one night of RES (4 h) and FRAG (8 h, 4 × 10 min awakenings) increased fatigue, depression and confusion compared to CONT (8 h). Likewise, Finan et al. (2015) reported reduced positive mood and increased negative mood following three consecutive nights of RES (3.5 h) or FRAG (8 h, 1 h awakenings); however, authors determined from these results that FRAG was more detrimental to mood states compared to RES. Mood changes, such as those observed following insufficient sleep, have been associated with an increased drive for food consumption, particularly of
calorie-dense foods, to alleviate feelings of fatigue and stress (Adam & Epel, 2007; Gibson, 2006; Moubarac, Cargo, Receveur, & Daniel, 2013; Oliver & Wardle, 1999); yet, the effects of sleep on mood are yet to be explored in conjunction with appetite-related responses. Moreover, despite previous findings indicating that exercise under normal sleep conditions induces positive changes in appetite-related hormones and perceived appetite (Broom et al., 2017; Deighton, Barry, Connon, & Stensel, 2013; Matos et al., 2017; Sim et al., 2014), and alleviates negative mood states (Basso & Suzuki, 2017; Paluska & Schwenk, 2000; Peluso & Andrade, 2005); these variables have not been observed together following exercise under conditions of sleep manipulation.

1.3 Exercise interventions for sleep and appetite regulation

1.3.1 Exercise intensity for sleep and appetite regulation

Although experimental evidence may suggest that sleep changes following exercise are small and vary in robustness (Kredlow et al., 2015), there remains to be a cohesive view that exercise provides acute and chronic benefits for sleep. It is important to consider that the varying results observed in previous studies likely occurred due to differences in exercise protocols, including exercise intensity, which is a continual debate in relation to sleep outcomes (Kredlow et al., 2015). For instance, findings report that moderate-intensity continuous exercise (MICE) appears more beneficial for sleep outcomes compared to high-intensity interval exercise (HIIE) (Passos et al., 2010), while others suggest that HIIE is required to induce greater sleep changes (Dworak et al., 2008; Horne, 1981). However, several studies have reported no sleep changes following acute exercise, regardless of intensity (Hayashi, Nishihira, Higashiura, & Sotoyuki, 2014; Rossi et al., 2010; Wong, Halaki, & Chow, 2013). The differences in results between studies may also be partly explained by the varying populations recruited, including children (Dworak et al., 2008), active adults (Bunnell, Bevier, & Horvath, 1983; Flausino et al., 2012; Horne & Staff, 1983), inactive adults (Hayashi et al., 2014; Wong et al., 2013) and clinical populations (Passos et al., 2010). Despite the volume of previous literature, the primary
population recruited are young, healthy adults with minimal sleep complaints, obtaining sleep up to 7 - 9 h regularly, and often meeting or exceeding exercise guidelines (Youngstedt, 2005). Therefore, the sleep improvements previously observed within these populations have been small due to a potential ‘ceiling effect’ (Youngstedt, 2005). Further, the effects of exercise intensity on sleep for young adults are unlikely to reflect potential sleep outcomes in middle-aged adults due to age-related sleep changes, including reduced sleep duration and proportion of stage N3 sleep, that occur from approximately 35 y of age (Copinschi et al., 2014). Arguably, it may be more advantageous to explore different exercise intensities that induce beneficial sleep outcomes in middle-aged individuals to reduce the influence of age-related decreases in sleep duration.

In addition to sleep, exercise intensity is also of ongoing interest with regards to appetite responses in which both MICE and HIIE have been shown to induce a downregulation of orexigenic signals (Balaguera-Cortes, Wallman, Fairchild, & Guelfi, 2011; Broom, Batterham, King, & Stensel, 2009; Sim et al., 2014). However, growing evidence suggests that higher intensities are associated with longer lasting reductions in perceived appetite and free-living energy intake (Broom et al., 2017; Sim et al., 2014; Thivel et al., 2012). Of interest, Sim et al. (2014) recruited overweight, inactive men (30 ± 8 y) who completed four experimental trials, including a non-exercise CONT, MICE, HIIE and very HIIE. This study showed that the higher the exercise intensity, the greater the reduction in acylated ghrelin after exercise, which was further associated with decreased free-living energy intake for up to 24 h (Sim et al., 2014). Conversely, other studies have indicated no difference in appetite responses following exercise at differing intensities (Martins et al., 2015; Howe et al., 2016). However, women were recruited for these studies and may have contributed to differences in findings from Sim et al. (2014) due to the natural hormonal changes that occur during the menstrual cycle (Dye & Blundell, 1997). Albeit, these studies have observed the effects of exercise on appetite-related hormones, perceived appetite and energy intake independent of sleep. Considering that appetite and sleep are closely
linked due to neuroendocrine and metabolic pathways, it may be beneficial to consider the responses and relationship of these domains when assessing the effects of exercise intensity.

### 1.3.2 Exercise time-of-day for sleep and appetite regulation

The ideal time-of-day to exercise to promote sleep has been debated for many years with both experts and the general public remaining divided, particularly with regards to evening exercise (Irish et al., 2015). The American Academy of Sleep Medicine (AASM, 2001) advise that evening HIE should be avoided due to increased arousal which may delay sleep onset and disrupt sleep continuity. However, more recent evidence suggests that evening HIE can be performed without disrupting subsequent sleep (Flausino et al., 2012; Hayashi et al., 2014; Myllymäki et al., 2012; Robey et al., 2013), and can even improve some sleep variables, including increased proportion of non-rapid eye movement (NREM) sleep (Robey et al., 2013), a reduction in awakenings (Alley et al., 2015), increased sleep efficiency (SE) and shortened sleep onset latency (SOL) (Roveda et al., 2011; Souissi et al., 2012). Robey et al. (2013) observed that HIE performed in the evening (1830 h) had no significant sleep differences for whole-night sleep compared to a non-exercise CONT; however, when the initial 180 min of sleep was analysed, there was a significant increase in NREM sleep and decrease in rapid eye movement (REM) sleep. These results suggest that evening HIE is more likely to alter sleep stages in the first 3 h of sleep rather than the entire subsequent sleep phase. Nonetheless, much like the current research investigating exercise intensity and sleep outcomes, the participants recruited for exercise time-of-day studies have been young adults without sleep complaints and mostly active/athletes (Alley et al., 2015; Myllymäki et al., 2011; Robey et al., 2013; Roveda et al., 2011; Souissi et al., 2012). Therefore, it may be difficult to extrapolate these previous observations to middle-aged adults. Hence, it is important to specifically recruit this population and examine the sleep responses to HIE at various times of the day to assess whether evening HIE attenuates or exacerbates the age-related reductions in sleep duration. Further, should evening HIE be safe to perform without disrupting subsequent sleep,
it may be an additional time-of-day for middle-aged adults to engage in exercise or provide an option for individuals who cannot otherwise schedule time to exercise (Buman et al., 2014).

The exploration of exercise time-of-day effects on appetite-related hormones, perceived appetite and energy intake are limited (Alizadeh, Mostafae, Mazaheri, & Younespour, 2015; Bilski et al., 2016; Maraki et al., 2005; O’Donoghue, Fournier, & Guelfi, 2010). The current literature indicates that aerobic exercise, regardless of time-of-day, either reduces perceived appetite (e.g. hunger and prospective food consumption) and energy intake (Bilski et al., 2016; Maraki et al., 2005), or has no significant effect compared to non-exercise CONT (Alizadeh et al., 2015; O’Donoghue et al., 2010). Further, one study which has investigated the effects of exercise time-of-day on leptin concentrations observed no significant response to a 30 s Wingate anaerobic test in the morning (MORN) or evening (EVEN) (Bilski et al., 2016). Although, there was a reduction in perceived hunger, prospective food consumption, and energy intake (ad-libitum meal) after exercise regardless of time-of-day (Bilski et al., 2016). Given the current discrepancies and limited number of studies, further investigation of appetite-related hormones, perceived appetite and energy intake responses following exercise performed at different times of day are needed.

1.4 Summary

Appetite-related hormones, perceived appetite and mood states are markedly altered by acute and prolonged sleep deprivation which has been shown to invoke an increased drive to consume energy-dense foods and enhance the need for snacking (Adam & Epel, 2007; Brondel et al., 2010; Nedeltcheva et al., 2009; Oliver & Wardle, 1999; Spiegel et al., 2004a; Spiegel et al., 2004b). Contrarily, participation in exercise has been shown to suppress orexigenic signals and energy intake (Broom et al., 2017; Sim et al., 2014), reduce negative mood states such as fatigue and stress, and increase feelings of vigour and esteem-affect (Basso & Suzuki, 2017; Hansen, Stevens, & Coast, 2001). However, the investigation
of exercise as a potential mitigator of detrimental appetite and mood responses to less than optimal sleep conditions has been largely unexplored. While there is consensus that exercise is beneficial for sleep duration and perceived sleep quality, optimal exercise intensity continues to be investigated due to conflicting findings suggesting that HIIE, compared to MICE, induces contradictory sleep changes (Dworak et al., 2008; Hayashi et al., 2014; Rossi et al., 2010). Further, the avoidance of HIE in the evening is still encouraged due to potential sleep disruptions (AASM, 2001; Irish et al., 2015) despite growing research that indicates otherwise (Alley et al., 2015; Hayashi et al., 2014; Oda & Shirakawa, 2014; Robey et al., 2013); thus, creating a barrier for exercise in an expanding time-restrained society (Gibala et al., 2012; Rajaratnam & Arendt, 2001; Sharma & Kavuru, 2010). In addition, evidence suggests that HIE induces lasting suppression of perceived appetite and energy intake compared to MICE (Broom et al., 2017; Holliday & Blannin, 2017; Matos et al., 2017; Sim et al., 2014; Thivel et al., 2012). However, exercise time-of-day effects on appetite regulation remain limited (Bilski et al., 2016; O’Donoghue et al., 2010). While important in their own right; the concurrent exploration of sleep and appetite responses to exercise intensity and time-of-day will provide greater insight into the convergent mechanisms which may attribute to chronic behaviours impacting health outcomes.

1.5 Statement of the Problem
As outlined above, there has been extensive research conducted for the purposes of exploring the respective relationships between sleep, appetite, and exercise; however, there remains to be limited, concurrent investigation of the potential multi-directional interaction between all three domains. Additionally, much of the current research has recruited young, active or athletic populations who obtain recommended sleep quantities and are without sleep complaints, thus creating a ‘ceiling effect’ (Youngstedt, 2005). Given that adults tend to experience age-related changes in sleep and exercise within in their mid-30s (Alves et al., 2011; ABS, 2013, 2015, 2018), it is pertinent to determine the
outcomes of sleep loss on dietary behaviour and hormone regulation in this population group. Further, through the exploration of alternative exercise interventions it may be possible to promote alternate exercise engagement strategies to assist in attenuating the age-associated reductions in sleep quantity, and improve appetite-related hormone profiles and dietary behaviours.

1.6 Thesis Aims
This thesis is comprised of three studies examining the physiological and behavioural interactions between sleep, appetite and exercise (Figure 1.1). Specifically, middle-aged men (35 - 65 y) were recruited for three separate studies to:

1. Explore the relationship between sleep, eating and exercise concurrently;
2. Investigate the effects of prolonged (three consecutive nights) sleep curtailment and extension on appetite-related hormones, perceived appetite and cravings, and mood states in inactive men;
3. Investigate the effects of exercise on appetite-related hormones, perceived appetite and cravings, and mood states following prolonged sleep curtailment and extension in inactive men;
4. Investigate the acute effects of exercise intensity and exercise time-of-day on subsequent sleep, appetite-related hormones, and perceived appetite in inactive men.
Study Aims and Hypotheses

The following hypotheses and aims were posited for each of the three studies to achieve the thesis aims:

Chapter Three: The effects of sleep restriction, fragmentation and extension on appetite and mood states before and after short-duration, vigorous exercise in inactive, middle-aged men

Research Hypotheses:

1. It was hypothesised that RES and FRAG compared to CONT and EXT:
   a. Would result in reduced anorexigenic hormone levels [leptin and total peptide tyrosine tyrosine (PYY$_{total}$)], and feelings of vigour and esteem-affect;
   b. Be associated with elevated acylated ghrelin, increased perceived hunger and food cravings, and heightened feelings of fatigue, stress and confusion;

2. Short-duration, vigorous exercise would reduce orexigenic signals and perceived hunger, and improve mood states for all trials; however, responses would be blunted following RES and FRAG compared to CONT, while EXT would provide additional benefits to appetite and mood variables induced by exercise.

Research Aims:

1. The aim of this study was to examine the effect of prolonged RES, FRAG and EXT on perceived appetite and appetite-related hormones, and mood states compared to CONT;

2. To investigate if short-duration, vigorous exercise (self-paced) alleviates or further exacerbates detrimental appetite and mood responses associated with RES and FRAG.
Chapter Four: High-intensity interval exercise induces greater acute changes in sleep, appetite-related hormones and free-living energy intake compared to moderate-intensity continuous exercise

Research Hypotheses:

1. It was hypothesised that both exercise intensities would improve sleep duration and quality compared to baseline (BASE), but HIIE would be more beneficial for sleep (increased stage N3 sleep and reduced arousals) and appetite parameters (anorexigenic changes in the circulating hormones and reduced energy intake) compared to MICE.

Research Aims:

1. This study aimed to compare the effect of HIIE and MICE on sleep characteristics, appetite-related hormones and free-living energy intake in inactive, middle-aged men.
Chapter Five: Evening high-intensity interval exercise does not disrupt sleep or alter energy intake despite changes in acylated ghrelin in middle-aged men

Research Hypotheses:

1. It was hypothesized that HIIE performed in the afternoon (AFT) and EVEN would increase the proportion of stage N3 sleep compared to BASE and MORN;
2. All exercise trials would induce favourable appetite changes (increased concentrating of anorexigenic hormones and reduced energy intake) due to the implementation of a standardised HIIE protocol.

Research Aims:

1. The aim of this study was to compare the effect of HIIE performed in the MORN, AFT and EVEN on sleep characteristics, appetite-related hormones and free-living energy intake in inactive, middle-aged men.
1.7 Limitations

- The results are applicable to inactive, middle-aged men (35 - 60 y) for all studies; therefore, extrapolation of results to other populations are restricted;
- The majority of participants were recruited from the local Bathurst region due to the extensive laboratory procedures implemented for the thesis; thus, there may be a potential bias and the extrapolation of results to other populations within different locations are restricted;
- It was assumed that participants followed instructions provided for all studies such as following fasting requirements prior to testing and reporting accurate food and fluid intake, including quantities and brands, however, could not be guaranteed;
- Self-reported data were subject to being under or over-reported; therefore, food, drink and activity records in Chapters Three to Five were considered carefully when interpreting results;
- The low specificity of actigraphy data limits the interpretation of sleep outcomes. Therefore, actigraphy results were interpreted to dichotomise sleep/wake classifications rather than sleep quality;
- For Chapter Three, EXT required participants to attempt sleep for 10 h per night; however, given that the participants were typically achieving 6.5 - 8.5 h (based on inclusion criteria) they were unable to attain this duration, perhaps due to obtaining sleep needs. Nonetheless, bed and wake time data verified that participants attempted to sleep for the required duration;
- While participants were requested to maintain habitual bed and wake times during the CONT and FRAG trials for Chapter Three, actigraphy data indicated that participants went to bed approximately 1 h earlier during FRAG compared to CONT. Therefore, while Chapter Three aimed to mimic real-life conditions, participants may have purposefully gone to bed earlier in anticipation for sleep disruption during FRAG;
- Due to recruitment and logistical constraints, laboratory testing for Chapter Three was completed in the morning which may not have indicated the extent of impact of RES or FRAG on hormone patterns and mood responses;
• Appetite-related hormones were measured before exercise, 30 min after exercise and the morning after exercise for Chapters Four and Five. These time points were chosen to capture both the acute and prolonged responses of acylated ghrelin, leptin and PYY\textsubscript{total}. Nonetheless, these time points were limited, and it is acknowledged that there may have been further variations in these hormones between time points which were not observed;

• Appetite-related hormones are subject to time-of-day and daily variations; therefore, these variations were considered when interpreting results, particularly in Chapters Four and Five;

• To avoid forced RES in Chapter Five on the night prior to HIIE, participants were required to undergo a 10 h overnight fast for MORN; whereas, for AFT and EVEN, participants fasted for 3 h prior. Therefore, it is possible that the differences in fasting affected the diurnal variations of acylated ghrelin, leptin, PYY\textsubscript{total} and glucose;

• A primary aim of this thesis was to observe free-living responses to enforced sleep manipulation and exercise interventions; therefore, abstinence from alcohol and caffeine were not enforced until the 24 h prior to experimental laboratory procedures. As such, it is possible that the consumption or non-consumption of these substances may influence appetite and mood responses.
1.8 Delimitations

- Multiple sources, such as radio and newspaper advertisement, websites, and word-of-mouth, were employed during the recruitment process for each of the studies to reduce the potential effects of location bias;

- Participants reporting use of any medications and/or on controlled diets, which alter sleep patterns and/or body mass were excluded from participating in any study;

- Testing sessions for Chapters Three, Four and Five were completed in a closed, controlled environment within an exercise science laboratory;

- Participants for Chapters Four and Five were instructed to provide accurate and detailed recordings of energy intake (food and drink bands and quantities) immediately after consumption;

- Appetite-related hormones are known to respond to acute external stimuli; therefore, three timepoints were designated to align with capturing acute responses to exercise and prolonged responses following subsequent sleep (Granados et al. 2012);

- Caffeine and alcohol intake may alter sleep patterns and appetite; therefore, participants were required to abstain from caffeine and alcohol 24 h prior to and day of testing for Chapters Three, Four and Five;

- Power analysis was conducted prior to all studies to determine the minimum number of participants required to achieve sufficient statistical power.
Chapter Two: Literature Review
Chapter 2: Literature Review

2.0 Introduction

Epidemiological evidence has shown that society has shifted into a 24 h environment whereby industrial production, and availability of commodities are continuous (Chaput, 2014). Although this shift has allowed for exponential technological and industrial growth, it has also led to increased stress and time restraints, particularly in relation to domestic and work-related responsibilities, thus, reducing leisure-time activities (Gibala et al., 2012; Rajaratnam & Arendt, 2001; Sharma & Kavuru, 2010). This societal shift has altered sleep patterns, appetite regulation and the engagement in exercise, and consequently changed the multi-directional relationship between these factors that facilitate synergistic physiological (e.g. neuroendocrine pathways) and psychological (e.g. mood states) processes (Keating et al., 2017; Kredlow et al., 2015). Sections 2.1 - 2.4 will discuss each of the primary factors of this thesis: sleep, appetite and exercise, and experimental measures that have allowed the investigation of the relationship between these lifestyle behaviours.

Across several decades there has been an increasing prevalence of chronically sleep deprived individuals with approximately 30 % of adults reporting less than 6 h of sleep per night (Adams et al., 2017; Chaput et al., 2009; Choi et al., 2008; Spiegel, Tasali, Leproult, & Van Cauter, 2009); which is more than 2 h less than the average reported sleep duration of adults in 1960 (Chaput et al., 2009). Both epidemiological and experimental studies have shown that insufficient sleep (< 6 h) facilitates non-homeostatic food intake, whereby emotional/psychological drive overpowers actual calories needed by the body (Section 2.5.1) (Chaput, 2014; Sharma & Kavuru, 2010). Furthermore, exposure to the modern obesogenic environment of readily accessible food (e.g. fast food chains) exacerbates the emotional drive to overconsume food when sleep deprived (Chaput, 2014; Koenders & van Strien, 2011). As will be discussed throughout this review, these types of behaviours have been associated with psychological and physiological perturbations such as increased stress, increases in body mass (particularly fat mass) and onset of comorbidities (e.g. cardiovascular disease and TIIDM) (Kredlow et
Further explanation of potential contributing factors to this increased drive for food consumption, including changes in cognitive functions involved in reward saliency & inhibitory control (Chaput, 2014), prolonged exposure to more palatable foods (Nedeltcheva et al., 2009), and an increase in orexigenic drive due to alterations of neuroendocrine pathways (Spiegel et al., 2004a; Spiegel et al., 2004b), will be provided in context of previous literature findings.

Exercise has been reported as one of the most important behaviours for obtaining optimal perceived sleep quality, as shown by Urponen et al. (1988) who reported that 30 - 33 % of participants indicated that exercise had the most positive effect on sleep. Nonetheless, many adults within society do not meet current exercise guidelines. For example, in Australia, 30 % of adults (18 - 64 y) do not achieve minimum exercise guidelines (≥ 150 min of moderate-intensity per week), while an additional 15 % are considered inactive (ABS, 2015). Peak inactivity occurs between 35 - 54 y of age (ABS, 2015), while 60 - 64 % of this age group also have at least one persistent sleep problem, such as not obtaining adequate sleep, feeling unrefreshed upon waking, or waking frequently during the night (Adams et al., 2017). Furthermore, as will become evident in this review, there remains to be a debate regarding optimal exercise intensity and time-of-day for improving sleep duration and quality, and inducing favourable appetite-related hormone profiles which support reduced perceptual appetite and energy intake.
Figure 2.1 Conceptual overview of the thesis and review of literature.
2.1 Sleep Physiology and Current Recommendations

Sleep is a complex, essential biological process needed to facilitate normal brain function, and overall health and wellbeing (AlDabal & BaHammam, 2011; Paterson, 2012). There are two interacting timekeeping mechanisms in the central nervous system which regulate sleep. These are circadian rhythmicity (i.e. biological clock) and sleep-wake homeostasis (i.e. duration of previous wake period) (Deboer, 2018; Leproult & Van Cauter, 2010). The suprachiasmatic nucleus (SCN), located in the hypothalamus, is considered the circadian pacemaker which regulates the 24 h rhythm of the sleep/wake cycle and communicates with peripheral oscillations to maintain internal homeostasis (Leproult & Van Cauter, 2010; Touitou, Reinberg & Touitou, 2017). The biological clock receives signals from the periphery and sends responding signals depending on factors such as the duration of the previous wake period, timing of food consumption and meal size, and time and intensity of physical activities (including organised exercise bouts) (Leproult & Van Cauter, 2010). During sleep, the body is relatively immobilised and consciousness ‘dulled’ as a result of voluntary muscle inactivation and decreased metabolic rate (Paterson, 2012). This induced state enables neurological regeneration and further development, processing of new information, consolidation of short and long-term memory, and cell restoration and repair, all of which are less effective during wake (AlDabal & BaHammam, 2011; Paterson, 2012).

Evidently, total sleep deprivation (TSD), RES and FRAG, impairs these essential processes which lead to acute and chronic diminishes in brain restoration and cognitive functioning (Wong et al., 2013); metabolic, endocrine and immune pathway function (Cappuccio, D’Elia, Strazzullo, & Miller, 2010); and increased risk of future comorbidities, such as obesity and TIIDM (Kredlow et al., 2015; Sharma & Kavuru, 2010).

Sleep consists of two states of distinct brain activity known as NREM and REM sleep (Copinschi et al., 2014). NREM sleep occupies 75 - 80 % of TST and comprises of three sleep stages (Rama et al., 2005). Stage N1 sleep is regarded as the lightest stage due to an association with drowsiness and slow rolling eye movements, which may cause brief phases of involuntary muscle twitches and wakefulness (Paterson, 2012). Stage N2 sleep is considered sleep onset proper whereby breathing and heart rate (HR) slows, and
muscle tone decreases (Paterson, 2012). The deepest stage of sleep is known as stage N3 sleep or slow wave sleep (SWS) during which time the body remains relatively immobile, and breathing and HR slows further to promote more efficient restorative effects of sleep to occur without disruption (Paterson, 2012). REM sleep occupies the remaining 20 - 25% of TST and the pattern of brainwaves during this sleep stage are considered to resemble wakefulness due to the high-frequency and low-voltage electroencephalography (EEG) patterns (Rama et al., 2005; Sharma & Kavuru, 2010). Further, REM sleep is characterised by vivid dreams, loss of muscle tone, and rapid eye movements (Sharma & Kavuru, 2010). Normal sleep physiology is characterised by a series of oscillations in which lighter sleep stages (stage N1 and N2 sleep) initiate sleep onset and precede SWS, while REM sleep and/or brief awakenings tend to occur following a bout of SWS (Copinschi et al., 2014). These sleep oscillations occur 4 - 6 times per night lasting approximately 90 min in duration (Copinschi et al., 2014; Rama et al., 2005). Further, the first half of sleep is predominantly NREM sleep; whereas, the second half of sleep is mostly REM sleep with increasing number and duration of awakenings as wake time nears (Figure 2.2) (Berry, 2012; Copinschi et al., 2014; Rama et al., 2005; Sharma & Kavuru, 2010).

![Figure 2.2 Hypnogram of typical sleep stages. N1: stage N1 sleep; N2: stage N2 sleep; N3: stage N3 sleep; R: rapid eye movement sleep; W: wake. Image, in part, from Berry (2012).](image)
Individual sleep needs vary greatly and are influenced by many factors, including age and sex (Sharma & Kavuru, 2010; Spiegel et al., 2005; Wong et al., 2013). When considering the influence of age, it is known that alterations in sleep duration begin to occur from approximately mid-30s. Specific observations include the dramatic decrease in SWS duration, followed by progressive declines in REM sleep and a proportional increase of time spent awake (Copinschi et al., 2014). Irrespective, the current recommendations for optimal sleep duration is 7 - 9 h per night for adults (18 - 60 y) (Watson et al., 2015). However, at least one third of adults do not achieve these sleep recommendations, in part due to economic demands, domestic responsibilities and social obligations (Beccuti & Pannain, 2011; Bei, Wiley, Trinder, & Manber, 2016; Cappuccio et al., 2010; Gibala et al., 2012; Rajaratnam & Arendt, 2001). This lifestyle shift is highlighted by Chaput et al. (2009) who indicated that mean sleep duration decreased by approximately 2 h from 1960 - 2009 (Chaput et al., 2009). Further, similar trends in sleep curtailment have been observed in other countries, including Australia (Adams et al., 2017), Korea (Choi et al., 2008) and France (de Santé, 2007). When observed in isolation, reduced sleep duration and quality may not appear important; however, there is an abundance of epidemiological and experimental evidence which shows that hormonal and behavioural perturbations associated with sleep loss may be the precursors to disease onset, such as obesity, T1IDM and depression (Buxton & Marcelli, 2010; Nedeltcheva et al., 2009; Spiegel et al., 2004b; Watson et al., 2015). Moreover, there is robust evidence to suggest that the incidents of these perturbations and comorbidities associated with short sleep duration and poor sleep quality are higher among middle-aged men compared to their female counterparts (Adams et al., 2017; AlDabal & BaHammam, 2011; Cappuccio et al., 2010; Ikehara et al., 2009; Imaizumi et al., 2015).

### 2.1.1 Measures of Sleep

**Polysomnography**

Polysomnography (PSG) is an advanced sleep monitoring system which is able to detect sleep stages and determine the presence of various sleep disorders (Nilius et al., 2017; Yow & Weng, 2011). Wake and
sleep stages have distinct brainwaves which can be identified by EEG channels (Berry, Brooks, & Gamaldo, 2016). During wake (with eyes closed), there is rhythmic alpha (α) activity (8 - 13 Hz) which primarily occurs within the occipital brain region (Carskadon & Dement, 2011). As such, signals mainly detected from O1 and O2 EEG leads are observed to determine the presence or absence of wake prior to sleep onset and to detect arousals during sleep (Figure 2.3) (Carskadon & Dement, 2011). Stage N1 sleep is represented by mostly low voltage, mixed frequency theta waveforms (4 - 7.99 Hz); thus, making it difficult to determine from EEG signals (Carskadon & Dement, 2011). Conversely, stage N2 sleep is more easily identified due to the occurrence of sleep spindles (14 - 16 Hz) and K-complexes (4 - 8 Hz) (Åkerstedt & Nilsson, 2003). Sleep spindles are characterised by bursts of rhythmical activity, with waxing and waning shapes lasting approximately 0.5 - 2.5 s, which are largely observed from centrally placed electrodes (Figure 2.3) (Lajnef et al., 2015; Silber et al., 2007). As defined by the AASM, K-complexes are a well delineated signal which starts with a negative sharp wave immediately followed by a positive component (Iber, Ancoli-Israel, Cheson, & Quan, 2007). Each K-complex is typically detected at maximum in the frontal region (e.g. F3 and F4 EEG leads) (Figure 2.3) (Lajnef et al., 2015). The precise role of K-complexes remains unknown as some studies report a potential arousal response, as they are often followed by micro-awakenings (Halász, 2005). Others have observed a potential sleep ‘protection’ mechanism (Jahnke et al., 2012) or have shown evidence that K-complexes represent isolated down-states (suppression of cortical activity) (Cash et al., 2009). Stage N3 sleep is identified by the appearance of delta waveforms (0.5 - 4 Hz) which can be likened to large mountain ranges (Figure 2.3) (Åkerstedt & Nilsson, 2003). Beta waveforms (13 - 30 Hz) are observed during REM sleep; however, it may look very similar to EEG patterns during wake (Fukuda, Wakakura, & Ishikawa, 1981; Herman, Barker, & Roffwarg, 1983). As such, to distinguish REM sleep from wake, PSG devices also detect eye movements using electrooculography (EOG) and electromyography (EMG) to assess muscle tone (Carskadon & Dement, 2011; Silber et al., 2007). EOG and EMG signals during REM sleep may display sawtooth waves and/or transient muscle activity respectively, which represents ‘phasic’ REM sleep (Silber et al., 2007). Conversely, during ‘tonic’ REM sleep EMG signals indicate the suppression of muscle tone (atonia) and there is a reduction in EOG
activity (Siegel, 2011). Additional equipment for a PSG device may include electrocardiography (ECG) to monitor heart rhythms, pulse oximetry to assess oxygen saturation, thoracic and abdominal belts to monitor respiratory effort, and a pressure transducer to measure nasal airflow.

PSG sleep monitoring may be performed using a range of devices which are classified into type I, II, III, and IV (from full PSG measures to single or dual bioparameter recordings) based on the number of sleep measures included. Due to the devices used in Chapters Five and Six, only type I and type II PSG devices will be discussed further. Type I PSG devices are mostly used in an attended laboratory setting as it includes all 12 EEG channels (F3 - M2, F4 - M1, C3 - M2, C4 - M1, O1 - M2, O2 - M1), bilateral EOG, chin and limb EMG, ECG (limb leads), and all respiratory measures with the primary role of diagnosis of sleep disorders. Comparatively, type II PSG devices are more portable and can be used outside of the laboratory setting. Generally, most type II devices have a reduced number of EEG, EOG, EMG and ECG channels compared to type I devices; yet, many of the units have the capacity to measure all respiratory variables, including oxygen saturation and nasal flow; thus also useful for detecting sleep disorders. The AASM regularly release guidelines for electrode and sensor placement to ensure PSG sleep studies are accurately conducted and during the time of data collection for Chapters Five and Six, the most recent guidelines were from Berry et al. (2016). The recommended electrode placement for EEG, bilateral EOG, and chin EMG are shown in Figure 2.3 and were used for the recording of PSG sleep studies in the current thesis. According to the AASM guidelines, sleep studies should be scored in 30 s epochs to accurately calculate sleep parameters (Berry et al., 2016). These parameters include time in bed (TIB), TST, SE [((TST - wake time)/sleep duration) × 100], SOL (time from lights out to the first epoch of sleep), REM onset latency, wake after sleep onset (WASO: total time awake after sleep onset), duration of sleep stages (absolute: min, relative to TST: %) and number of arousals (Paterson, 2012; Yow & Weng, 2011).
There are advantages and disadvantages for the use of PSG in a laboratory setting and/or a home setting. Specifically, an attended laboratory PSG study allows technicians to monitor signal quality, replace or reposition faulty sensors, and adjust the amplitude of declining signals during a sleep study to reduce the risk of signal loss and/or study failure (Iber et al., 2004). However, given the unfamiliarity of the laboratory setting to participants, sleep may be disrupted, thus data recorded will not reflect ‘normal’ sleep patterns (Iber et al., 2004; Portier et al., 2000). Conversely, unattended home studies are suggested to provide a better reflection of sleep given that food and drink consumption, sleep duration, sleep-stage distribution, and body position are more likely to be consistent with normal nocturnal behaviours (Iber et al., 2004).

Several investigations have incurred poor signal quality resulting in the exclusion of 5 - 20 % of home-based PSG recordings (Fry et al., 1998; Portier et al., 2000; Redline et al., 2000); however, others have observed no difference in signal quality or accuracy between attended laboratory studies and unattended home studies (Mykytyn, Sajkov, Neill, & McEvoy, 1999). Therefore, home-based PSG studies are a viable option for research purposes and the risk of study failure can be reduced when the devices are attached by an experienced person. The Alice PDx (Philips Respironics, Murrysville, PA) is a portable type II or III device which has been validated for recording sleep parameters (Grover et al., 2009). This device has the capacity to obtain measures for EEG, EOG, ECG, EMG, oral-nasal airflow, respiratory effort, and oxygen saturation (Grover et al., 2009). Grover et al. (2009) observed high agreement for sleep stages and respiratory events between the Alice PDx (type II - III) and the Alice 5 (type I) (Kappa: 0.89). Also, Nilius et al. (2017) reported a significant correlation for obstructive sleep apnoea (OSA) diagnosis between in-laboratory Alice PDx (ICC: 0.95) and at-home Alice PDx (ICC: 0.79) studies compared to a reference in-laboratory type I PSG device. As such, the Alice PDx would be a suitable portable PSG device for unattended home-based sleep studies for the purpose of excluding sleep disorders and the assessment of sleep stages.
Although PSG is considered the gold standard procedure for the assessment of sleep and diagnostic purposes, its use is somewhat limited until signs of sleep disorders are presented, particularly within the general population. This is, in part, due to the cost associated with conducting, scoring and analysing PSG sleep studies, the expertise required to attach the PSG device to increase reliability of testing, and the size of the device and cords attached which may disrupt normal sleep patterns (Van De Water, Holmes, & Hurley, 2011; Zinkhan et al., 2014). Experimental recommendations suggest that BASE assessments are obtained across two nights to reduce the ‘first night effect’ which refers to a series of phenomena, including reduced TST, REM sleep and SE, increase stage N1 sleep, WASO, and latency to stage N3 and REM sleep (Curcio et al., 2004). As for long-term sleep monitoring, the last several decades have seen the development of other sleep monitoring equipment, including actigraphy devices, which compared to many PSG units, are more cost effective, do not require expertise for attachment, and are compact thus reducing the risk of sleep disruption (Ancoli-Israel et al., 2003; Sadeh, 2011; Weiss, Johnson, Berger, & Redline, 2010).
Figure 2.3 10-20 system for electrode placement for electroencephalography (EEG), electrooculography (EOG) placement, and chin electromyography (EMG) placement for polysomnography (PSG) sleep studies.
Actigraphy devices are designed to monitor movement using accelerometry for extended periods of time and may be worn on the wrist, ankle or torso depending on size and structure of the device (Ancoli-Israel et al., 2003; Sadeh, 2011; Zinkhan et al., 2014). Actigraphy is predominantly recorded via a wrist-worn device capable of recording sleep and wake periods, typically in 30 s - 1 min epochs (Knutson et al., 2007a). Recorded actigraphy data are scored by computerised software into sleep or wake epochs as determined by activity counts. Although actigraphy data cannot determine sleep stages, there are many sleep quantity parameters which can be calculated. These parameters include TIB (starting from the moment of intention to fall asleep and concluding with the final arising), TST (TIB - SOL - WASO - wake time), SOL (bedtime - sleep onset), SE [time in bed spent asleep, (TST/TIB) × 100)], WASO (total time spent awake after sleep onset), and number of awakenings (total awakenings excluding final wake time) (Buysse et al., 2006; Knutson et al., 2007a).

The validity and reliability between actigraphy devices do differ considerably and there are some concerns regarding the use of actigraphy to monitor sleep among special populations (e.g. persons with depression or schizophrenia) (Sadeh, 2011). However, the efficacy of actigraphy sleep monitoring has been shown to be satisfactory for healthy populations with no or minor sleep complaints (Kosmadopoulos et al., 2014; Paquet, Kawinska, & Carrier, 2007). For instance, Paquet et al. (2007) compared three nights of actigraphy and PSG recordings in 15 healthy adults aged 20 - 60 y without the presence of sleep disturbances. Overall, the Actiware medium threshold algorithm compared to PSG recordings had high sensitivity (95 %) and accuracy (91 %), but low specificity (54 %) (Paquet et al., 2007). As such, actigraphy data allows for a dichotomous sleep/wake classification but is unable to identify sleep stages; therefore, interpretation of results should be done so with caution. Also, for individual sleep parameters the Actiware medium threshold algorithm indicated a shorter SOL and higher number of awakenings compared to PSG data; however, TST and SE were similar between devices (Paquet et al., 2007). Nonetheless, findings from Ross
and Janiszewski (2008) suggest that to achieve greater reliability for actigraphy recorded TST, WASO and SE, data should be averaged over a minimum of seven days; whilst, SOL may require 14 days for adequate reliability, particularly in older adults. Knutson et al. (2007a) further support that to improve the validity of actigraphy, sleep should be measured and mean calculated for recordings of 7 - 14 days in duration.

**Sleep Questionnaires**

The Pittsburgh Sleep Quality Index (PSQI) is a self-rated questionnaire developed in 1989 to assess perceived sleep quality within the prior month (Appendix B) (Buysse et al., 1989). The PSQI assesses seven key sleep components, including SOL, TST, habitual SE, sleep disturbances, use of sleeping medication and daytime dysfunction. Although each component is given an individual score, a ‘global’ score is also calculated by tallying the seven components (Smyth, 2007). A global score of ≤ 5 indicates ‘good’ sleep; whereas, a global score of ≥ 5 indicates ‘poor’ sleep (Smyth, 2007). A high degree of internal consistency for the seven components of the PSQI have been previously reported with an overall reliability coefficient of 0.83, and the test-retest reliability was also high as determined by a correlation coefficient of 0.85 (Buysse et al., 1989).

Designed in 1991, the Epworth Sleepiness Scale (ESS) measures sleep propensity using a self-administered questionnaire and consists of eight situations involving low levels of stimulation, relative immobility and relaxation (Johns, 1991). The overarching question of this tool considers the tendency or ‘chance of dozing’ whilst an individual engages with each of the presented situations, for example ‘sitting and reading’ or ‘watching television’. Individuals are required to score each situation on a 0 ('no chance of dozing') - 3 ('high chance of dozing') Likert scale (Appendix B) (Johns, 1991). At the completion of the questionnaire, scores are tallied and interpreted following a standardised scale: 0 - 5 ‘normal daytime sleepiness’, 6 - 10 ‘higher normal daytime sleepiness’, 11 - 12 ‘mild excessive daytime sleepiness’, 13 - 15 ‘moderate excessive daytime sleepiness’, and 16 - 24 ‘severe excessive daytime sleepiness’ (Johns, 1991).
When developing this questionnaire, Johns (1991) demonstrated that the ESS and the respiratory disturbance index (as determined by PSG data) were significantly correlated ($r = 0.550$, $p < 0.001$) for OSA patients. Therefore, the ESS is a simple and reliable method for measuring daytime sleepiness in adults with and without sleep complaints (Johns, 1992).

### 2.2 Eating Behaviour

Appetite is defined as the desire to satisfy a bodily need, particularly for food (Oxford Dictionary, 1999); however, eating behaviour and dietary preference greatly influence one’s appetite. Eating behaviour and dietary preference refers to an individual’s food choices and prioritisation of the consumption of certain foods as opposed to others (Paspala et al., 2012). These factors develop from infancy and are influenced by both biological factors (e.g. genetics) and environmental factors, including social and emotional effects of food, food availability, and availability of time to prepare meals (Chaput, 2014; Paspala et al., 2012). As such, when examining eating behaviour, researchers tend to concurrently investigate perceived appetite (e.g. hunger and fullness), frequency and size of eating episodes (e.g. snacking vs main meals), food choices (e.g. high-fat or low-fat, fast food or home-cooked meals), variety of foods accepted and enjoyed, palatability of diet, and day-to-day variability of food consumed (Arora, 2006; Champagne et al., 2013).

Feelings of hunger have been shown to rise and fall within the 24 h cycle and tend to follow a typical pattern which aligns with the circadian patterns of key appetite-related hormones as are discussed in Section 2.5.1 (Birketvedt et al., 2012; Copinschi et al., 2014; Scheer, Morris, & Shea, 2013). Scheer et al. (2013) presented findings of a morning trough in feelings of hunger before a progressive rise which tended to peak in the evening at approximately 2000 h, independent of time since waking, previous meals and total calories consumed. In conjunction, the authors noted that feelings of hunger appear to influence the desire and cravings for energy-dense foods while the desire for nutritionally rich foods (e.g. fruit and vegetables) lack circadian input (Scheer et al., 2013). Thus, these findings suggest that feelings of hunger
are, in part, controlled by an endogenous circadian rhythm. Although, there is a large volume of findings which also suggest that perceived appetite and food choices/cravings are strongly influenced by sleep quality and quantity (Brondel et al., 2010; Chaput, 2014; Morselli et al., 2012; Nedeltcheva et al., 2009; Spiegel et al., 2004a; Spiegel et al., 2004b). In particular, RES and FRAG have been associated with increased feelings of hunger, desire for calorie-dense foods and increased snacking (Brondel et al., 2010; Gonnissen et al., 2013; Nedeltcheva et al., 2009; Spiegel et al., 2004b).

There appears to be two predominant precursors that influence eating behaviour during periods of insufficient sleep, which include homeostatic stimuli (e.g. changes in key appetite-related hormones as will be discussed in Section 2.5.1) and hedonic stimuli, such as timing and opportunity for eating, and changes in mood/emotional state (Chaput, 2014). Acute experimental studies have shown the emotional disturbances induced by sleep deprivation, such as increased stress and depression, are associated with changes in food preferences, especially for energy-dense carbohydrate foods (e.g. sweet, salty and starchy food), and an increased drive to consume food which overpowers actual energy needs (Sharma & Kavuru, 2010). Spiegel et al. (2004b) clearly demonstrated food preference changes following two nights of RES (4 h) compared to two nights of EXT (10 h) in which participants reported an increased desire for ‘unhealthy’ foods, such as sweets (33 %), salty food (45 %) and starchy food (33 %); however, cravings for ‘healthy’ foods did not increase to the same extent (17 - 21 %). Likewise, Nedeltcheva et al. (2009) presented findings which support the notion that increased energy intake is associated with insufficient sleep, as there was an increase in high-carbohydrate snack consumption during 14 nights of 5.5 h sleep despite no change in total energy intake. The authors suggested that these findings may have been a result of prolonged exposure to more palatable food (Nedeltcheva et al., 2009).

Chronic sleep loss has been further associated with increases in perceived appetite, cravings and consumption of ‘unhealthy’ foods, increased eating time and frequency, increased feelings of fatigue and
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reduced motivation to engage in physical activity (Gutierrez & Willoughby, 2010; Kim, DeRoo, & Sandler, 2011; Morselli, Leproult, Balbo, & Spiegel, 2010; Schubert, Sabapathy, Leveritt, & Desbrow, 2014); thus, increasing the risk of developing comorbidities (Knutson et al., 2007b; Patel et al., 2006; Sharma & Kavuru, 2010; Zanuto, Christofaro, & Fernandes, 2014). This perpetuating behaviour leads to detrimental changes in the synthesis, release and sensitivity of central and peripheral appetite-related hormones in which orexigenic signals are uncontested due to an inhibition of anorexigenic signals (e.g. leptin) (Kelly et al., 2009; Paspala et al., 2012). These changes in hormone concentration and sensitivity have been further associated with a particular eating behaviour profile in which certain populations (e.g. overweight and obese persons) present low dietary restraint, and high disinhibition and hunger as distinguished by the Three-Factor Eating Questionnaire (TFEQ: Section 2.2.1) (Stunkard & Messick, 1985). Therefore, individuals with excessive fat mass tend to be at greater risk of overeating, especially in opportunistic situations (e.g. events where palatable foods are readily available) and have an increased awareness or concern with the palatability of food (Blundell, 2006). As such, it may be pertinent to intervene with this deleterious ‘cyclic’ behaviour by implementing a multi-factorial intervention for overlapping physiological mechanisms which may induce favourable eating behaviour and food choice outcomes.

2.2.1 Measures of Eating Behaviour

Visual Analogue Scales

Visual analogue scales (VAS) investigate perceived appetite variables such as hunger and fullness; and are often measured in conjunction with appetite-related hormone concentrations (Broom et al., 2017; Deighton et al., 2013; Holliday & Blannin, 2017; Howe et al., 2016; Martins et al., 2015; Panissa et al., 2016; Sim et al., 2014). The validity of VAS (100 mm straight line), for the purpose of assessing perceived appetite, were examined by Flint et al. (2000) in which each variable was expressed by a ‘most positive’ and ‘most negative’ anchor (Appendix B).
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The perceived appetite variables that were assessed by authors included hunger, satiety, fullness, prospective food consumption, the desire to eat something ‘fatty’, ‘salty’, ‘sweet’ or ‘savoury’, and the palatability of the test meal (Flint et al., 2000); however, for the purpose of this thesis only data for hunger, fullness, prospective food consumption and desire to eat will be reviewed. 55 men (26 ± 1 y, BMI: 23 ± 0.3 kg·m²) were recruited and assigned into one of two groups, which included a diet and non-diet group, and tested on two separate days in which VAS was recorded prior to a standardised breakfast meal, and every 30 min after from 1000 - 1400 h (Flint et al., 2000). The authors reported that there were no between-group differences for the coefficient of repeatability of the appetite groups (non-dieters: 24 - 30 mm, dieters: 23 - 30 mm) (Flint et al., 2000). As for validity, post-prandial 4.5 h VAS ratings were more strongly correlated to energy intake ($r = -0.52 - 0.53$) compared to pre-lunch ($r = -0.43 - 0.39$) and pre-post difference ($r = 0.33 - 0.40$) ratings (Flint et al., 2000). Furthermore, stronger correlations were observed on the second test day ($r = -0.52 - 0.51$) compared to the first test day ($r = -0.44 - 0.48$) (Flint et al., 2000). The findings by Flint et al. (2000) indicate that VAS scores are reliable and valid for appetite research and do not appear to be influenced by prior diet standardisation; however, authors encourage the consideration of the sensitivity and study power of specific appetite variables used in respective studies.

Eating Behaviour Questionnaires

The TFEQ is a widely used psychometric tool for the assessment of eating behaviour (Stunkard & Messick, 1985). The TFEQ consists of 51 questions which calculate individual scores for three eating behaviours, including dietary restraint (low: < 6; medium: 6 - 11; high: > 11), disinhibition (low: < 8; medium: 8 - 12; high: > 12) and hunger (low: < 5; medium: 5 - 8; high: > 8) (Stunkard & Messick, 1985). Dietary restraint is referred to as a conscious awareness of, and choices/strategies implemented to avoid weight gain; therefore, an example of high restraint behaviour may include avoiding fattening foods or purposefully eating smaller portions (Bryant, King, & Blundell, 2008). Conversely, disinhibition is described as the tendency to overeat and/or consume food opportunistically in ‘obesogenic’ environments such as social
gatherings wherein palatable foods are likely available in abundance (Bryant et al., 2008). Lastly, the hunger variable considers the extent to which perceived feelings of hunger evoke food intake, such that individuals may consume more than three meals per day (Bryant et al., 2008). The reliability and validity of the TFEQ was conducted in 1985 in which 220 men ($n = 97$) and women ($n = 123$) aged 17 - 77 y completed the questionnaire (Stunkard & Messick, 1985). The authors observed strong coefficient $\alpha$ reliability for all participants: restraint ($\alpha = 0.93$), disinhibition ($\alpha = 0.91$) and hunger ($\alpha = 0.85$); for dieters: restraint ($\alpha = 0.79$), disinhibition ($\alpha = 0.84$) and hunger ($\alpha = 0.83$); and non-dieters: restraint ($\alpha = 0.92$), disinhibition ($\alpha = 0.84$) and hunger ($\alpha = 0.87$) (Stunkard & Messick, 1985). Although the TFEQ has received some criticism in the past (Shearin et al., 1994) and may not provide specific explanation of disordered eating behaviour (Bond, McDowell, & Wilkinson, 2001), it remains to be an appropriate tool to assess general constructs of eating behaviour in healthy populations.

The Food Cravings Questionnaire (FCQ) is a multi-dimensional psychometric tool which examines two primary factors, including i) stable features of food cravings across time and during different situations (i.e. trait), and ii) features of food cravings influenced by contextual, psychological and physiological state changes (i.e. state) (Cepeda-Benito, Gleaves, Williams, & Erath, 2000). The tool was first developed by Cepeda-Benito et al. (2000) who recruited 290 students aged 17 - 33 y to examine the final validity and reliability of both the FCQ-Trait and FCQ-State. The FCQ-Trait assesses the frequency of nine ‘stable’ factors which include 1) having intentions and plans to consume food, 2) anticipation of positive reinforcement that may result from eating, 3) anticipation of relief from negative states and feelings as a result of eating, 4) lack of control over eating, 5) thoughts or preoccupation with food, 6) cravings as a physiological state, 7) emotions that may be experienced before or during food cravings or eating, 8) cues that may trigger food cravings and 9) guilt from cravings and/or giving into them (Cepeda-Benito et al., 2000). The authors reported sound internal consistency for the FCQ-Trait as indicated by the Goodness-of-Fit Index (0.83) and the Normed-Fit Index (0.98), and high test-retest reliability overall ($r = 0.88$) and
for each subscale ($r = 0.72 - 0.88$) (Cepeda-Benito et al., 2000). The second tool, FCQ-State, can be manipulated and repeated to examine the effect of specific food groups (e.g. sweet or savoury) or foods (e.g. chocolate or fruits) which may stimulate food cravings depending on external influences (e.g. sleep conditions, mood states, exercise, fasting) (Cepeda-Benito et al., 2000). FCQ-State examines five ‘unstable’ factors, including 1) an intense desire to eat, 2) anticipation of positive reinforcement that may result from eating, 3) anticipation of relief from negative states and feelings as a result of eating, 4) lack of control over eating, and 5) craving as a physiological state (hunger). The Goodness-of-Fit Index (0.91) and Normed-Fit Index (0.98) indicated that the FCQ-State also had good internal consistency; however, the test-retest reliability was not stable over time which supports the tool’s sensitivity to situational characteristics of food cravings (Cepeda-Benito et al., 2000). Thus, these findings suggest that the FCQ-Trait and FCQ-State are appropriate for the examination of stable food cravings and food cravings in response to external stimulus in non-clinical populations. Moreover, the FCQ-Trait was shown to strongly correlate with TFEQ subscales in which cravings were related to disinhibition and hunger, and largely uncorrelated with dietary restraint (Cepeda-Benito et al., 2000). Therefore, the use of these tools concurrently may provide a greater understanding of eating behaviour.

**Self-Reported Records**

Energy intake has been recorded using self-reported methods, such as 24 h food recall and seven day diaries, due to having sound reliability and reasonable agreement between repeated records of up to two years apart (de Castro, 2006). Despite the efficacy of self-reported food records, there is evidence that several populations tend to under report total energy intake or may be selective in their reporting of types of food (e.g. under report ‘unhealthy’ foods and over report ‘healthy’ foods) (de Castro, 2006). Populations which are likely to under report energy intake and ‘unhealthy’ food items are overweight or obese people (Trabulsi & Schoeller, 2001), individuals who self-restrict energy intake (e.g. high restraint) (Asbeck et al., 2006), or those who have a greater need of approval from others, typically women (Scagliusi
et al., 2003). As such, characteristic differences (e.g. eating behaviour) when comparing energy intake between groups, such as men and women, or active and inactive individuals; and day-to-day variation in diet for the same person should be considered when interrupting results (Black & Cole, 2001; Champagne et al., 2013). Thus, to improve food record accuracy, it is suggested that more detail is provided, such as food/fluid brands, individual foods consumed and portion size of meals.

2.3 High-intensity interval exercise versus moderate-intensity continuous exercise

Regular exercise is promoted widely for holistic health management as it supports weight management (i.e. maintenance of higher muscle mass and lower fat mass) (Donnelly et al., 2009), disease prevention and treatment (Fogelholm, 2010; Heden et al., 2013a), and psychological wellbeing (Paluska & Schwenk, 2000). Compared to many health interventions, exercise is relatively inexpensive, non-invasive, has minimal side effects, and can be varied as fitness improves for continued enjoyment/adherence (Alves et al., 2011). As discussed in Section 1.1, the exercise recommendations for Australian adults outline that a minimum of 150 min of moderate-intensity aerobic exercise should be completed each week (Department of Health, 2017). Traditional forms of exercise which have been encouraged and are still promoted include MICE, such as walking/jogging or cycling, at an intensity which can be maintained for a set duration (Keating et al., 2017). However, longer durations of MICE (e.g. ≥ 60 min) have been shown to have greater benefits for physiological and neurological variables compared to shorter duration MICE (e.g. 20 - 30 min) (Grego et al., 2004; Jakicic et al., 2003; Wenger & Bell, 1986). For instance, in a 12 month intervention study, which recruited 201 inactive women, participants who were assigned moderate-intensity (rating of perceived exertion, RPE: 10 - 12), high duration (20 - 60 min) exercise had a mean weight reduction of 8.2 kg compared to 6.3 kg for the moderate-intensity (RPE: 10 - 12), moderate duration (20 - 40 min) exercise group (Jakicic et al., 2003). Further, Wenger and Bell (1986) reported that despite minimal differences in \( \dot{V}O_{2\text{max}} \) improvements between 15 - 25 min and 25 - 30 min MICE, significant increases in \( \dot{V}O_{2\text{max}} \) are observed for MICE durations that exceeded 35 min. Together, these findings support the notion that longer duration MICE is more beneficial than shorter durations; however, there appears to be a growing
number of adults reporting a ‘lack of time’ as a major barrier to exercise (Gibala et al., 2012). As such, many adults do not meet exercise guidelines as shown by global and national statistics wherein 30 - 31% of adults are considered physically inactive (ABS, 2015; Hallal et al., 2012). Moreover, in Australia, adults of 35 - 54 y appear to be the least active compared to 18 - 34 y and 55 - 64 y adults (ABS, 2015). To mediate this statistic, there has been growing interest and promotion of short-duration, HIIE in the last several decades. Although this type of exercise was predominantly utilised in athletic development and training prior to this, HIIE is becoming a common alternative to longer duration, MICE among general and clinical populations (Gibala & McGee, 2008).

The typical characterisation of HIIE is brief, intermittent bursts of vigorous activity, interspersed by periods of passive or low-intensity active rest (Boutcher, 2010; Gibala et al., 2012). The protocols for this type of training vary considerably depending on intensity, duration, number of sprints and duration of recovery intervals (Boutcher, 2010; Gibala et al., 2012). Growing evidence has suggested that HIIE induces significant changes in physiological (e.g. \( \dot{V}O_{2\max} \)), performance (power output) and health-related markers (e.g. glycaemic control, lipid levels, increased muscle mass, decreased fat mass) (Heydari, Freund, & Boutcher, 2012; Hwang, Wu, & Chou, 2011; Little et al., 2014; Racil et al., 2013; Tjønna et al., 2009; Wisløff et al., 2007), and that this type of training is reportedly more enjoyable compared to MICE; which may lead to greater adherence. For example, Little et al. (2014) recruited ten inactive, overweight/obese adults (41 ± 11 y, BMI: 36 ± 7 kg·m\(^2\)) and observed that post-prandial glucose responses were significantly reduced following a lunch and dinner meal for both HIIE (10 × 1 min, 90 % peak HR, 1 min rest) and MICE (30 min at 65 % peak HR); however, post-prandial glucose remained lower after breakfast the following day for HIIE only. Moreover, 12 weeks of HIIE (3 × 20 min per week, 8 s at 80 - 90 % peak HR, 120 - 130 rpm: 12 s at 40 rpm) performed by overweight men (25 ± 5 y, BMI: 28 ± 1 kg·m\(^2\)) was shown to significantly reduce total body mass (-1.5 kg), total fat mass (-2 kg), visceral fat (+17 %), and increase muscle mass in the lower limbs (+0.4 kg) and trunk (+0.7 kg) compared to a non-exercise CONT (Heydari et al., 2012).
Likewise, Trapp et al. (2008) observed significant reductions in total body mass (-1.5 kg) and fat mass (-2.5 kg) following 15 weeks of HIIE (20 min, 60 x 8 s sprints: 12 s recovery at 20 - 30 rpm) compared to MICE (10 - 20 min at 60 % VO\textsubscript{2peak}) and a non-exercise CONT in young women (22 ± 1 y, 24 ± 2 kg·m\textsuperscript{2}). While transient, the appetite-related responses following HIIE appear to be longer lasting compared to MICE (Broom et al., 2017; Sim et al., 2014; Thivel et al., 2012); however, exercise time-of-day has been largely unexplored in relation to appetite responses (Section 2.7) (Alizadeh et al., 2015; Bilski et al., 2016; Maraki et al., 2005; O’Donoghue et al., 2010).

2.4 Wellness and Mood States
Given the intertwining and bi-directional relationship between mood and sleep, and appetite and exercise, it is difficult to distinguish the initial provocateur which signals a cascade of physiological and behavioural changes. Nonetheless, from the perspective of mood states, there is a strong association between psychological distress (i.e. increased feelings of negative moods and stress) and compromised sleep (Kahn et al., 2013), poor eating behaviour (Adam & Epel, 2007; Gibson, 2006; Macht, 2008), and disengagement from physical activity in lieu of sedentary activities (Berger & Motl, 2000). In relation to sleep, negative mood (e.g. high stress, anxiety) can lead to difficulties in obtaining adequate sleep (Kahn et al., 2013). For instance, an early study by Gross and Borkovec (1982) recruited 38 college women (good sleepers) who were randomly assigned to one of three trials, including i) sleep only (normal sleep), ii) speech only (participants informed that they would be asked to make a speech soon after wakening) and iii) speech and topic (informed of speech topic prior to sleep). Sleep was recorded via PSG and revealed that participants that were in the speech and topic group experienced a delay in SOL compared to the sleep only and speech-only groups (Gross & Borkovec, 1982). Similarly, 14 adults (32 ± 12 y) who obtained 6 - 9 h sleep regularly participated in a study which compiled of two conditions, i) experimental failure condition (received a fail mark for cognitive task) and ii) control condition (received a pass mark for cognitive task) (Vandekerckhove et al., 2011). The authors reported that there was a significant delay for SOL, increase in WASO and REM sleep awakenings, and decrease in TST, SE, REM sleep and stage N3 sleep.
following the experimental failure condition compared to the control condition (Vandekerckhove et al., 2011). Collectively, these studies demonstrate the clear decline in sleep duration and continuity when negative mood states and stress are heightened, while further evidence indicates that consequential insufficient sleep perpetuates negative moods, thus repeating the cycle (Giacobbi et al., 2005; Kahn et al., 2013). As for appetite, stress appears to be a significant contributor to inducing obesogenic behaviours, such as the overconsumption of palatable, energy-dense foods (Chaput, 2014; Koenders & van Strien, 2011). Koenders and van Strien (2011) examined the associations between lifestyle factors, including overweight, eating behaviour and emotional eating among a cohort of 1 562 banking employees (men: n = 963, women: n = 599, 44 ± 9 y). High emotional eating was strongly correlated with an increase in body mass index (BMI) (p = 0.01); whereas, high sporting engagement was associated with weight loss but not to the same extent (p = 0.07) (Koenders & van Strien, 2011). Researchers suggested that emotions may drive overweight and obese individuals to overeat, resulting in further weight gain, and while higher exercise participation may attenuate this, it does not solve the issue (Koenders & van Strien, 2011). Nonetheless, exercise has been shown to concurrently reduce negative mood states and improve positive mood states (Basso & Suzuki, 2017; Paluska & Schwenk, 2000; Peluso & Andrade, 2005; Salmon, 2001; Sonstroem & Morgan, 1989). It is believed that exercise may provide a distraction from unfavourable stimuli (Morgan, 1985), encourage the completion of challenging activities (North, McCullagh, & Tran, 1990) and encourage social relationships that may lead to mutual support among exercising individuals (Ransford, 1982). As such, it is possible that mood, sleep, appetite and exercise work in a multifaceted fashion; whereby, direct and indirect effects on each factor may improve or induce detrimental outcomes on the other. Therefore, further research which investigates these factors simultaneously may be warranted to provide a holistic strategy for improving overall health and wellbeing.
2.4.1 Measures of Mood and Wellness

Mood State Questionnaires

The wellness questionnaire presents five wellbeing items, including two physical items (fatigue and general muscle soreness) and three psychological items (sleep quality, stress and mood) (Appendix B) (McLean et al., 2010). Each item is scored on a 1 (‘feeling as bad as possible’) to 5 (‘feeling as good as possible’) Likert scale and total mood disturbance (TMD) is calculated from the sum of all five items in which higher scores indicate low TMD (positive outcome) and low scores indicate high TMD (negative outcome) (McLean et al., 2010). The wellness questionnaire was customised by McLean et al. (2010) following recommendations by Hooper et al. (1995) who reported that fatigue, muscle soreness, sleep quality and stress were key determinants of overtraining among elite athletes. Key findings from this study revealed wellbeing changed for five, seven and nine day microcycles during the 2008 National Rugby League season whereby high TMD was observed at one day post-match for all microcycles and that second day TMD was lower for the five day mircocycle compared to seven and nine day microcycles (McLean et al., 2010). Although many studies have used this questionnaire to assess the wellbeing of athletes, it is a simple tool which may also quickly and effectively measure the wellbeing of general populations prior to, during and following exercise interventions.

The Profile of Mood States (POMS) - short version was adapted from the original 65-item questionnaire used extensively in exercise and sports science research (McNair, Lorr, & Droppleman, 1971). The short version consists of 40 items which assess seven mood subscales, including negative mood states (tension, anger, fatigue, depression, confusion) and positive mood states (esteem-affect, vigour) (Grove & Prapavessis, 1992). Each of the 40 items are scored on a 0 (‘not at all’) to 4 (‘extremely’) Likert scale based on how an emotion best describes an individual’s feelings at that moment (Grove & Prapavessis, 1992). Although each subscale can be assessed in isolation, a TMD score can also be calculated using the following formula: 

\[ \text{TMD} = (\text{tension} + \text{depression} + \text{anger} + \text{fatigue} + \text{confusion}) - (\text{vigour} + \text{esteem-affect}) \]
Unlike the wellness questionnaire, higher scores for TMD indicates greater mood disturbances and lower TMD scores indicate decreased mood disturbance. To examine the reliability and validity of the POMS, it was administered to 45 female netball players immediately after a competition that was either won or lost (Grove & Prapavessis, 1992). The authors reported that reliability coefficients (Cronbach’s α) for the subscales ranged from α = 0.664 - 0.954 (mean: 0.798); while, for validity, all subscales, except for fatigue, were significantly different between participants who won or lost their competition (Grove & Prapavessis, 1992). Therefore, the 40 item POMS questionnaire has been widely accepted for the assessment of mood states in sport and exercise settings (Blanchard et al., 2002; Hayakawa, Takada, Miki, & Tanaka, 2000; Robson-Ansley, Gleeson, & Ansley, 2009).

The Perceived Stress Scale (PSS) is a psychological tool which examines self-reported stress based on responses to ten situations that may arise in day-to-day situations scored on a 0 (‘never’, no stress) to 4 (‘very often’, high stress) Likert scale (Appendix B) (Cohen, Kamarck, & Mermelstein, 1983). The sum of all scores are tallied to provide an overall score for perceived stress wherein lower scores indicate low perceived stress and higher scores indicate high perceived stress (Cohen et al., 1983). Reliability testing of the PSS was conducted following administration of the tool to three separate groups, including two samples of college students (n = 332, n = 114) and a group of participants in a smoking cessation program (n = 64) (Cohen et al., 1983). The authors reported that the coefficient α reliability for the PSS revealed α = 0.84 for the first student group, α = 0.85 for the second student group and α = 0.86 for the smoking cessation group (Cohen et al., 1983). However, the test-retest correlations were significantly different between 82 of the students (r = 0.85) and the smoking cessation group (r = 0.55) when retested after six weeks (Cohen et al., 1983). These differences may not be surprising given that the PSS requires participants to consider the prior month when answering; therefore, responses may change due to unexpected life events (e.g. celebration or loss) or lifestyle changes, such as quit smoking. The PSS remains to be a widely used tool due to the simplistic format, ease of scoring, and the efficient examination of the
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degree to which situations in an individual’s life are appraised as stressful (Buman et al., 2010; Davis & Sandman, 2010; Ward Thompson et al., 2012).

2.5 Sleep Quality and Quantity

2.5.1 The role of sleep and circadian rhythms for appetite control

Energy homeostasis is regulated by a complex physiological system consisting of neurological networks, metabolic substrates and gut hormones which work simultaneously in the modulation of appetite stimulation and satiety effects (Sharma & Kavuru, 2010; Wynne et al., 2005). Moreover, many of the endocrine-metabolic systems involved in appetite control are partially regulated by sleep-wake homeostasis (Copinschi et al., 2014). This relationship has been examined more thoroughly in the last two decades; whereby, sleep curtailment appears to be strongly associated with disruptions of energy metabolism (Copinschi et al., 2014). Further, key appetite-related hormones, including ghrelin, leptin and PYY_total and glucose have received particular attention given that sleep loss affects the amplitude and circadian variation of these hormones and metabolites (Copinschi et al., 2014; Spiegel et al., 2004b).

Ghrelin is an orexigenic peptide which is predominantly released from the gastric oxyntic cells and endocrine glands located in the gastric mucosa (Heden et al., 2013b; Marzullo et al., 2008; Toshinai et al., 2007). The primary functions of ghrelin include, but are not limited to, the stimulation of hunger and food consumption, decreasing energy expenditure and promoting fat retention (Morselli et al., 2012). While ghrelin exists in two forms (acylated and non-acylated), there is a consensus that acylated ghrelin is responsible for its orexigenic effects (Spiegel et al., 2011). This appetite-related peptide is highly dependent on meal ingestion and fasting; however, there is evidence which suggests that ghrelin may follow a circadian rhythm in which there is an early morning nadir before a progressive increase until mid-afternoon (Copinschi et al., 2014; Espelund et al., 2005). Additionally, in relation to sleep, a nocturnal rise in acylated ghrelin has been associated with increases in NREM sleep (especially stage N3 sleep),
decreases in REM sleep, and modulating the release of growth hormone (GH), particularly in men (Dzaja et al., 2004; García-García, Juárez-Aguilar, Santiago-García, & Cardinali, 2014; Nass et al., 2008; Weikel et al., 2003). For instance, Dzaja et al. (2004) reported that peak GH levels during a nocturnal sleep bout (8 h) was positively correlated ($r = 0.705$) with ghrelin secretion during the initial 4 h of sleep; while Nass et al. (2008) have shown that there is an increase in circulating acylated ghrelin 0 - 60 min prior to GH secretory events during normal sleep conditions. While the link is not fully understood, García-García et al. (2014) propose that ghrelin modulates the release of nocturnal GH to stabilise glucose during overnight fasting as GH can exert direct metabolic effects on fat and muscle tissues.

There are many anorexigenic hormones, including leptin and PYY$_{total}$, which oppose the appetite-related actions of ghrelin to regulate hunger/energy intake and satiety/energy expenditure. Leptin is an adipose-derived hormone which is released to inhibit hunger and food intake, increase energy expenditure and promotes fat utilisation (Morselli et al., 2012). Specifically, leptin binds to receptors in the hypothalamus to simultaneously inhibit orexigenic neuropeptides (e.g. neuropeptide Y: NPY and agouti-related peptide: AgRP) and stimulate anorectic neuropeptides (e.g. proopiomelanocortin: POMC, cocaine- and amphetamine-related transcript: CART and alpha-melanocyte-stimulating hormone: α-MSH) (Arora, 2006; Paspala et al., 2012). Unlike ghrelin, leptin appears to follow a more defined circadian pattern in which there is a morning nadir between 0800 - 1200 h before progressively increasing until approximately 2400 - 0400 h (Arora, 2006; Copinschi et al., 2014; Morselli et al., 2012; Saad et al., 1998; Sinha et al., 1996). In addition to appetite, there appears to be sleep-associated functions of leptin, including the promotion of nocturnal NREM sleep (especially stage N3 sleep) and reduction of REM sleep (García-García et al., 2014; Willie, Chemelli, Sinton, & Yanagisawa, 2001). As such, the circadian pattern of leptin likely prompt different diurnal and nocturnal functions wherein daytime concentrations are lower to allow feeding, while evening satiation effects of leptin support sleep onset and stage N3 sleep (Mullington et al., 2003).
Both ghrelin and leptin responses, in association with perceived appetite, have been explored during TSD studies which show the effects of extreme sleep loss on appetite-related variables (Table 2.1) (Dzaja et al., 2004; Mullington et al., 2003; Pejovic et al., 2010; Schmid et al., 2007; Schmid et al., 2008; Simon et al., 1998). While some of these studies have indicated that there are no significant changes in leptin or ghrelin during TSD compared to CONT (Dzaja et al., 2004; Pejovic et al., 2010), several studies have indicated changes in hormone concentrations (Mullington et al., 2003; Schmid et al., 2008), and changes in the amplitude and circadian rhythms of leptin (Simon et al., 1998). An early study recruited seven young men to undergo one night of TSD and examined leptin concentration, peak concentration time and peak concentration value compared to CONT (8 h) results (Simon et al., 1998). The authors reported that despite no between-trial difference in mean leptin concentration or peak concentration level, the peak concentration time occurred later during TSD (0429 h) compared to CONT (0239 h) (Simon et al., 1998). Likewise, Mullington et al. (2003) observed changes in leptin among ten men (27 y, 26 kg·m⁻²) who remained awake for 88 h whereby the amplitude of leptin significantly decreased during TSD compared to CONT (3 nights of 8 h sleep) and a recovery sleep trial (REC: 3 nights of 7 - 14 h sleep). Interestingly, authors observed a rebound in leptin concentration during the second and third night of REC (Mullington et al., 2003), which indicated that the effects of TSD on leptin are transient and reversed when recommended sleep quantities are obtained. Unlike these studies, Schmid et al. (2008) did not observe significant differences in leptin between CONT (1 night of 7 h sleep), TSD (1 night of no sleep) or RES (1 night of 4.5 h sleep). However, following both TSD and RES, ghrelin was significantly reduced compared to CONT, which was further associated with an increase in perceived hunger for TSD only (Schmid et al., 2008). While the observed differences for leptin and ghrelin between studies are likely due to dissimilar protocols (TSD duration), they also represent an extreme state of sleep behaviour which would not be sustained in ‘real world’ situations. Therefore, much of the literature is now focussing on understanding the effects of sleep curtailment (RES and FRAG) on appetite-related hormones, perceived appetite and energy intake, as these sleep conditions may better reflect epidemiological sleep data (Adams et al., 2017; Chaput et al., 2009; Hillman & Lack, 2013). Several recent reviews have indicated that the changes in
neurohormonal markers of appetite during sleep loss are more equivocal than previously suggested (Capers et al. 2015; Zhu et al. 2019). However, discussion of the individual experimental studies is warranted to justify the studies of this thesis.

RES and FRAG have been associated with changes in appetite and hormone concentrations related to positive energy balance (increased energy intake and reduced energy expenditure) (Table 2.1). Spiegel et al. (2004b) presented a clear association between acute RES, deleterious hormone changes and a consequential increase in appetite. In young healthy men, two consecutive nights of 4 h RES induced an 18 % reduction in leptin concentration and 28 % increase in circulating ghrelin compared to 10 h EXT (Spiegel et al., 2004b). These results were further associated with a 24 % increase in perceived hunger, 23 % increase in overall appetite, and 33 - 45 % increase in desire for calorie-dense, carbohydrate foods (Spiegel et al., 2004b). Although this study did not measure energy intake, the results demonstrated negative changes in appetite control which would suggest a detrimental impact on weight management long-term. To support this, several studies have indicated an increase in energy intake following RES (Bosy-Westphal et al., 2008; Brondel et al., 2010; Nedeltcheva et al., 2009). Bosy-Westphal et al. (2008) and Nedeltcheva et al. (2009) have previously reported increases in energy intake after RES despite no significant difference in leptin and ghrelin concentrations following either RES or CONT. Nedeltcheva et al. (2009) further noted that during RES, participants consumed the additional calories predominantly from snacks. Moreover, following one night of 4 h RES, Brondel et al. (2010) observed increased hunger for up to 12 h which was associated with a 22 % increase in energy intake and a significant increase in fat intake (3 %). These results suggest that just minute changes in hormones after RES may trigger a positive energy balance response, perhaps due to an increased need to maintain wakefulness (Chaput, 2014; Willyard, 2008).
A primary mechanism which has been postulated for the link between sleep curtailment and deleterious metabolic effects is the upregulation of orexin neuronal activity which is directly modulated by circulating ghrelin, leptin and glucose (Adamantidis & de Lecea, 2008, 2009; García-Garcia et al., 2014). The orexin neuropeptide system has been shown to play a significant role in feeding and sleep-wakefulness regulation; thus, it may coordinate both physiological and behavioural responses due to the interactions of sleep and appetite (Willie et al., 2001). Decreased leptin, and increased ghrelin and glucose, as observed during TSD and sleep curtailment, increase orexin neuronal excitability which in turn promotes eating behaviour, arousal and increased energy expenditure (Adamantidis & de Lecea, 2008; Burdakov, Gerasimenko, & Verkhratsky, 2005; Sakurai, 2007; Williams et al., 2008). Further, the triggering of orexin circuitry during prolonged sleep curtailment is believed to result in a positive feedforward loop which could worsen subsequent sleep due to a disinhibition of sleep-promoting circuits (e.g. GABAergic/glycinergic cells located in the anterior hypothalamus) (Adamantidis & de Lecea, 2008; Lu & Greco, 2006). As such, the adverse positive feedforward loop is a primary factor for the association between insufficient sleep and the risk of becoming overweight or obese (García-García et al., 2014). Even so, there are several studies which have observed increases in perceived hunger and food consumption despite no significant changes in ghrelin or leptin (Bosy-Westphal et al., 2008; Markwald et al., 2013; Nedeltcheva et al., 2009; Omisade, Buxton, & Rusak, 2010; Pejovic et al., 2010; Simpson, Banks, & Dinges, 2010). As such, there is likely to be other contributing factors to the increased drive to eat when sleep deprived, such as changes in other appetite-related hormones (e.g. PYY_total) (Magee et al., 2009) or hedonic stimuli, such as changes in mood/emotional state as discussed in Section 2.5.2 (Chaput, 2014).

PYY is a peripheral anorexigenic hormone released from L-cells within the intestinal mucosa of the ileum and large intestine (Ueno, Yamaguchi, Mizuta, & Nakazato, 2008). Unlike leptin, which follows a clear circadian pattern, the secretion of PYY is dependent on the number of calories ingested and rises within 15 min of meal initiation, reaching peak levels within 90 mins of meal cessation and may remain elevated
for up to 6 h (Adrian et al., 1985). Due to responding more acutely to energy intake and expenditure, it is unlikely that PYY follows a circadian rhythm. However, three studies have investigated the effects of RES on PYY in isolation (St-Onge et al., 2012b) and in conjunction with perceived appetite (Magee et al., 2009) and energy intake (Markwald et al., 2013). Ten men (20 ± 2 y) completed two sleep trials, which involved either two nights of RES (5 h) or one night of EXT (8 - 10 h), to examine ghrelin, leptin, PYY and perceived appetite responses (Magee et al., 2009). Although ghrelin and leptin were not significantly different between sleep trials, authors did report significantly lower PYY for RES (78 ± 43 pg·ml⁻¹) compared to EXT (90 ± 54 pg·ml⁻¹), in conjunction with reduced satiety (VAS, RES: 1.8 ± 1.2 cm vs EXT: 2.6 ± 1.4 cm) (Magee et al., 2009). Conversely, St-Onge et al. (2012b) reported no significant difference for PYY₃₋₃₆ between RES (3 nights of 4 h sleep) and CONT (3 nights of 9 h sleep). Markwald et al. (2013) also showed no difference in PYY following RES (5 nights of 5 h) sleep compared to BASE (5 nights of 9 h sleep) despite an increase in carbohydrate consumption (RES: 394 ± 119 g, BASE: 357 ± 109 g). St-Onge et al. (2012b) and Markwald et al. (2013) recruited both men (n = 14, n = 8) and women (n = 13, n = 8); therefore, the discrepancies between studies suggests that there are sex-differences to sleep-induced hormone responses. This is supported by the PYY results of men and women in each respective study in which RES appeared to decrease PYY for men (4 pg·ml⁻¹ and ≈ 3 pg·ml⁻¹); whereas, PYY results for women were slightly elevated in both studies (7 pg·ml⁻¹ and ≈ 10 pg·ml⁻¹) compared to BASE/CONT (Markwald et al., 2013; St-Onge et al., 2012b). Given these inconsistencies, potential mechanisms underlying PYY responses to sleep loss remain to be identified and warrant further exploration; however, it should be acknowledged that in the current thesis PYY₅₀₃ was only measured in a male cohort.
Table 2.1 Current literature on the effects of total sleep deprivation, sleep restriction and sleep fragmentation on appetite regulation.

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Sleep Intervention</th>
<th>Appetite Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total Sleep Deprivation</td>
<td></td>
</tr>
<tr>
<td>Simon et al. (1998)</td>
<td>n = 7 men</td>
<td>CONT (8 h; 2300 - 0700 h; 1 night) TSD (8 h circadian phase shift; 0700 - 1500 h; 1 day)</td>
<td>Leptin Mean Peak time Peak level</td>
</tr>
<tr>
<td></td>
<td>21 - 25 y</td>
<td>TSD (8 h)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI 22 kg·m²</td>
<td>TSD (8 h circadian phase shift; 0700 - 1500 h; 1 day)</td>
<td></td>
</tr>
<tr>
<td>Mullington et al. (2003)</td>
<td>n = 10 men</td>
<td>CONT (8 h; 3 nights) TSD (88 h) REC (7 h or 14 h; 3 nights)</td>
<td>Leptin ↓ TSD</td>
</tr>
<tr>
<td></td>
<td>27 y</td>
<td>TSD (88 h)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI 26 kg·m²</td>
<td>REC (7 h or 14 h; 3 nights)</td>
<td></td>
</tr>
<tr>
<td>Dzaja et al. (2004)</td>
<td>n = 10 men</td>
<td>CONT (10 h; 1 night) TSD (1 night)</td>
<td>Ghrelin NSD</td>
</tr>
<tr>
<td></td>
<td>28 y</td>
<td>TSD (11 h)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI 24 kg·m²</td>
<td>TSD (11 h)</td>
<td></td>
</tr>
<tr>
<td>Schmid et al. (2007)</td>
<td>n = 10 men</td>
<td>CONT (7 h; 1 night) TSD (1 night)</td>
<td>Glucose NSD Hunger ↑ TSD</td>
</tr>
<tr>
<td></td>
<td>25 y</td>
<td>TSD (1 h)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI 24 kg·m²</td>
<td>TSD (1 h)</td>
<td></td>
</tr>
<tr>
<td>Schmid et al. (2008)</td>
<td>n = 9 men</td>
<td>CONT (7 h; 1 night) TSD (1 night)</td>
<td>Leptin NSD Hunger ↑ TSD</td>
</tr>
<tr>
<td></td>
<td>24 y</td>
<td>TSD (1 h)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI 24 kg·m²</td>
<td>TSD (1 h)</td>
<td></td>
</tr>
<tr>
<td>Schmid et al. (2008)</td>
<td>n = 21 normal-sleepers (11 women)</td>
<td>TSD and no nap (n = 11, 40 h)</td>
<td>Leptin NSD Hunger NSD</td>
</tr>
<tr>
<td></td>
<td>24 - 25 y</td>
<td>TSD and nap (n = 10, 40 h)</td>
<td></td>
</tr>
<tr>
<td>Schmid et al. (2008)</td>
<td></td>
<td>TSD and no nap (n = 11, 40 h)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TSD and nap (n = 10, 40 h)</td>
<td></td>
</tr>
</tbody>
</table>
### Sleep Restriction

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Protocol</th>
<th>Outcome Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guilleminault et al. (2003)</td>
<td>n = 8 young men</td>
<td>CONT (8.5 h; 3 nights)</td>
<td>Leptin ↓ RES</td>
</tr>
<tr>
<td>Spiegel et al. (2004a)</td>
<td>n = 11 men</td>
<td>BASE (8 h; 3 nights)</td>
<td>Leptin: Mean ↓ 19% RES</td>
</tr>
<tr>
<td></td>
<td>22 y</td>
<td>RES (4 h; 6 nights)</td>
<td>Maximum ↓ 26% RES</td>
</tr>
<tr>
<td></td>
<td>BMI 23 kg·m²</td>
<td>EXT (12 h; 7 nights)</td>
<td>Rhythm ↓ 20% RES</td>
</tr>
<tr>
<td>Spiegel et al. (2004b)</td>
<td>n = 12 men</td>
<td>RES (4 h; 2 nights)</td>
<td>Leptin ↓ RES</td>
</tr>
<tr>
<td></td>
<td>22 y</td>
<td>EXT (10 h; 2 nights)</td>
<td>Ghrelin ↑ RES</td>
</tr>
<tr>
<td></td>
<td>BMI 24 kg·m²</td>
<td></td>
<td>Hunger ↑ RES</td>
</tr>
<tr>
<td>Bosy-Westphal et al. (2008)</td>
<td>n = 14 women</td>
<td>CONT (&gt; 8 h; 2 nights)</td>
<td>Leptin ↑ RES</td>
</tr>
<tr>
<td></td>
<td>28 y</td>
<td>RES (7 h; 6 h; 6 h; 4 h)</td>
<td>Ghrelin NSD</td>
</tr>
<tr>
<td></td>
<td>BMI 26 kg·m²</td>
<td>REC (&gt; 8 h; 2 nights)</td>
<td>Hunger NSD</td>
</tr>
<tr>
<td>Magee et al. (2009)</td>
<td>n = 10 men</td>
<td>RES (5 h; 2 nights)</td>
<td>Leptin ↑ RES</td>
</tr>
<tr>
<td></td>
<td>20 y</td>
<td>EXT (8 - 10 h; 1 night)</td>
<td>Ghrelin NSD</td>
</tr>
<tr>
<td>Nedeltcheva et al. (2009)</td>
<td>n = 11 adults (5 women)</td>
<td>CONT (8.5 h; 14 nights)</td>
<td>Leptin ↑ RES</td>
</tr>
<tr>
<td></td>
<td>39 y</td>
<td>RES (5.5 h; 14 nights)</td>
<td>Ghrelin NSD Ei</td>
</tr>
<tr>
<td>Schmid et al. (2009)</td>
<td>n = 10 men</td>
<td>CONT (7 h; 1 night)</td>
<td>Leptin ↑ RES</td>
</tr>
<tr>
<td></td>
<td>25 y</td>
<td>RES (4.5 h; 1 night)</td>
<td>Ghrelin NSD Ei (snacks)</td>
</tr>
<tr>
<td>Schmid et al. (2009a)</td>
<td>n = 15 men</td>
<td>CONT (8 h; 2 nights)</td>
<td>Leptin ↑ RES</td>
</tr>
<tr>
<td></td>
<td>27 y</td>
<td>RES (4 h; 2 nights)</td>
<td>Ghrelin NSD Ei</td>
</tr>
</tbody>
</table>

**CHO**, **FAT**, **PRO**, **NSD**: Not specified
<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Intervention</th>
<th>Key Measures</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brondel et al. (2010)</td>
<td>12 men, BMI 22 kg·m²</td>
<td>CONT (8 h; 1 night)</td>
<td>Hunger</td>
<td>↑ RES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RES (4 h; 1 night)</td>
<td>EI</td>
<td>↑ RES</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CHO</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FAT</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PRO</td>
<td>NS</td>
</tr>
<tr>
<td>Nedeltcheva et al. (2010)</td>
<td>10 overweight adults, 3 women, BMI 27 kg·m²</td>
<td>CONT and caloric restriction (8.5 h; 14 nights)</td>
<td>Leptin</td>
<td>NSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RES and caloric restriction (5.5 h; 14 nights)</td>
<td>Ghrelin</td>
<td>↑ RES</td>
</tr>
<tr>
<td>Omisade et al. (2010)</td>
<td>15 women, BMI 24 kg·m²</td>
<td>CONT (10 h; 2 nights)</td>
<td>Leptin</td>
<td>↑ RES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RES (3 h; 1 night)</td>
<td>Hunger</td>
<td>NSD</td>
</tr>
<tr>
<td>Simpson et al. (2010)</td>
<td>136 participants, 65 women, BMI 25 kg·m²</td>
<td>CONT (10 h; 2 nights)</td>
<td>Leptin</td>
<td>↑ RES</td>
</tr>
<tr>
<td>van Leeuwen et al. (2010)</td>
<td>15 men, BMI 23 kg·m²</td>
<td>CONT (8 h; 2 nights)</td>
<td>Leptin</td>
<td>↑ RES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RES (4 h; 5 nights)</td>
<td>Hunger</td>
<td>NSD</td>
</tr>
<tr>
<td>St-Onge et al. (2012b)</td>
<td>27 adults, 13 women, BMI 24 (23) kg·m²</td>
<td>CONT (9 h; 3 nights)</td>
<td>Leptin</td>
<td>NSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RES (4 h; 3 nights)</td>
<td>Ghrelin</td>
<td>↑ RES (men)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Acylated</td>
<td>NSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ghrelin</td>
<td>NSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PYY&lt;sub&gt;3-36&lt;/sub&gt;</td>
<td>NSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Glucose</td>
<td>NSD</td>
</tr>
<tr>
<td>Markwald et al. (2013)</td>
<td>16 adults, BMI 23 kg·m²</td>
<td>BASE (9 h; 5 nights)</td>
<td>Leptin</td>
<td>NSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RES (5 h; 5 nights)</td>
<td>Ghrelin</td>
<td>NSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PYY</td>
<td>NSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CHO</td>
<td>↑ RES</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FAT</td>
<td>NSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PRO</td>
<td>NSD</td>
</tr>
</tbody>
</table>
## Sleep Fragmentation

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Conditions</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonnissen et al. (2013)</td>
<td>n = 12 men, 23 y, BMI 24 kg·m²</td>
<td>CONT (8 h; 1 night), FRAG (8 h; alarms every 90 min; 1 night)</td>
<td>Ghrelin, Leptin, Glucose, Hunger, Fullness, Desire to eat</td>
</tr>
</tbody>
</table>

**BASE**: baseline sleep; **BMI**: body mass index; **CHO**: carbohydrates; **CONT**: control/normal sleep; ↓: decrease; **EI**: energy intake; **EXT**: sleep extension; **FAT**: fats; **FRAG**: sleep fragmentation; >: greater than; **h**: hours; ↑: increase; **kg·m²**: kilograms per metre squared; **min**: minutes; **n**: number of participants; **NSD**: no significant difference; **%**: percent; **PRO**: proteins; **PYY**: peptide tyrosine tyrosine; **REC**: sleep recovery; **RES**: sleep restriction; **TSD**: total sleep deprivation; **y**: years.
2.5.2 The influence of sleep on wellness and mood states

There is strong evidence to show that insufficient sleep is detrimental for mood and emotional wellbeing due to increases in negative feelings of fatigue and stress, and a reduction in positive feelings, including vigour (Kahn et al., 2013). Current literature has primarily focussed on the effects of TSD on mood states (Ikegami et al., 2009; Meney et al., 1998; Paterson et al., 2011; Scott, McNaughton, & Polman, 2006; Selvi, Gulec, Agargun, & Besiroglu, 2007; Skein et al., 2011; van Heugten–van der Kloet, Giesbrecht, & Merckelbach, 2015); however, as these sleep conditions may not reflect ‘real world’ situations, research has been conducted to investigate the effects of RES (Ablin et al., 2013; Dinges et al., 1997) and FRAG on mood states (Bonnet, Berry, & Arand, 1991; Gonnissen et al., 2013; Kahn et al., 2014). Further, several studies have investigated the potential benefits of EXT on mood states (Kamdar, Kaplan, Kezirian, & Dement, 2004; Mah, Mah, Kezirian, & Dement, 2011).

The protocols which have examined mood states in response to TSD have ranged in duration from approximately 24 - 66 h (Table 2.2). Despite slightly different findings between each of these studies, the vast consensus is that TSD is detrimental for mood and emotional wellbeing due to a rise in negative and fall in positive mood states (Meney et al., 1998; Paterson et al., 2011; Scott et al., 2006; Selvi et al., 2007; Skein et al., 2011; van Heugten–van der Kloet et al., 2015). Furthermore, a study by Paterson et al. (2011) suggested that mood states may continue to worsen as TSD is extended. To expand, 62 young adults (22 y) were recruited to participate in three separate trials, including i) BASE (normal sleep, 1 night), ii) TSD-1 (continuous wakefulness for 39 - 42 h) and iii) TSD-2 (continuous wakefulness for 63 - 66 h), in which mood states were recorded every 2 h during wake (Paterson et al., 2011). While increased depression and anger scales were similar between the two TSD protocols, all other scales were worsened to a greater extent for TSD-2 compared to TSD-1, including activation, happiness, fatigue and fear, which were calculated using the following equation: \[\text{[(end score - baseline score)/baseline} \times 100]\] (Paterson et al., 2011). TSD studies
are further supported by sleep curtailment (RES and FRAG) research in which similar deleterious mood state responses have been reported (Ablin et al., 2013; Finan et al., 2015; Selvi et al., 2007).

An early study by Dinges et al. (1997) restricted the sleep of 16 young adults (23 y) by 50 % of normal sleep duration for seven consecutive days to examine self-reported changes in mood states using the POMS. At the completion of RES, authors reported a significant increase in fatigue ($p = 0.0001$), confusion ($p = 0.001$), tension ($p = 0.008$) and TMD ($p = 0.0001$), in conjunction with reduced vigour ($p = 0.002$) compared to CONT (Dinges et al., 1997). Likewise, Ablin et al. (2013) observed mood states in 87 young adults ($27 \pm 6$ y, men: $n = 48$, women: $n = 44$) that were equally assigned to one of four groups, i) CONT (normal sleep and exercise, 10 days), ii) RES (6 h, 10 days), iii) exercise cessation (no running, 10 days) and iv) RES and exercise cessation (6 h sleep and no running, 10 days). Interestingly, authors reported that there was an interaction between sex, RES and exercise cessation for TMD; whereby, women reported an increase in TMD regardless of whether exercise cessation was presented or not, while men showed increased TMD when sleep restriction was combined with exercise cessation (Ablin et al., 2013). These results suggest that when men are experiencing periods of sleep loss, short bouts of exercise may alleviate associated increases in negative mood states.

Researchers have suggested that sleep loss results in heightened negative moods and reduced positive emotions due to alterations in neural networks (Gujar, Yoo, Hu, & Walker, 2011; Schloegl et al., 2011; St-Onge et al., 2014; Yoo et al., 2007). Yoo et al. (2007) recruited 28 participants ($22 \pm 3$ y) to explore the ability of the brain to form new episodic memories in the absence of prior sleep (35 h TSD) and reported that negative mood pathways in the amygdala to the medial prefrontal cortex, became less inhibited during sleep loss. Further research has also shown that reward-relevant pathways (e.g. mesolimbic) become highly active during sleep loss which enhances pleasure-evoking stimuli, such as ‘unhealthy’ foods (Gujar et al., 2011; Schloegl et al., 2011; St-Onge et al., 2014). It also appears that the encoding of neutral
and positive memories are impaired during insufficient sleep; whereas negative memory is unaffected (Walker & Tharani, 2009). Collectively, these results indicate the increased susceptibility of seeking out pleasure-based reward, such as palatable foods, during sleep loss, which may contribute to long-term weight gain associated with prolonged feelings of negative moods (Adam & Epel, 2007; Kahn et al., 2013).

While sleep curtailment, regardless of whether sleep is shortened or disrupted, induces negative mood responses (Table 2.2), there is some evidence to suggest that FRAG may be more detrimental compared to RES (Finan et al., 2015). Firstly, a pilot study by Kahn et al. (2014) observed similar increases in negative mood scales and decreases in positive mood scales following a single night of FRAG (8 h sleep with awakenings every 90 min) and RES (4 h sleep, 0300 - 0700 h). Specifically, the combined mood effects for the sleep manipulation (SM) trials compared to CONT (8 h) showed an increase in confusion (SM: 1.08, CONT: 0.84), depression (SM: 0.99, CONT: 0.70) and fatigue (SM: 2.20, CONT: 1.77), and a decrease in vigour (SM: 1.59, CONT: 1.92) (Kahn et al., 2014). Finan et al. (2015) investigated the effects of FRAG and RES separately on mood states. 62 adults (26 ± 6 y) were assigned to either CONT (normal sleep, 3 nights), FRAG (awakenings at hourly intervals, 3 nights) or RES (≈ 3.5 h, 3 nights) during which time positive and negative moods were assessed daily using the POMS - bipolar questionnaire (Finan et al., 2015). While mood states did not differentiate between sleep manipulation trials following the initial night, as insufficient sleep continued, responses between trials deviated (Finan et al., 2015). Specifically, following FRAG, the positive mood scale declined by ≈ 20 and the negative mood scale increased by ≈ 12; whereas, after RES there was a decrease of ≈ 8 for positive and an increase of ≈ 10 for negative mood scales (Finan et al., 2015). The authors proposed that these findings were likely due to a disruption in stage N3 sleep; however, this potential mechanism has not been largely examined in the literature and requires further exploration (Finan et al., 2015; Paterson, 2012).
While much of the literature has explored the detrimental effects of sleep loss on mood states, several studies have investigated the potential therapeutic effects of EXT on mood and wellbeing (Kamdar et al., 2004; Mah et al., 2011). First, 15 college students were recruited to participate in five nights BASE (≈ 7 h sleep) followed by ≤ 48 nights of EXT in which participants were instructed to obtain as much sleep as possible (mean: ≈ 9 h) (Kamdar et al., 2004). Students were assessed at BASE, mid-EXT and after EXT whereby the POMS fatigue scale decreased by 10 and the POMS vigour scale increased by 7 (Kamdar et al., 2004). In a similar study, 11 young basketball players (19 ± 1 y, BMI: 24 ± 1 kg·m²) completed BASE (6.5 h sleep) varying in duration and EXT (8.5 h sleep) for ≈ 5 - 7 weeks (Mah et al., 2011). The authors indicated that POMS mood subscales were significantly improved from BASE to the end of EXT. Specifically, there was an increase in vigour (+ 6.4), and decreases in fatigue (- 6.8), tension (- 2.5), depression (- 2.36), anger (- 3.2), confusion (- 2.8) and TMD (- 24.1) (Mah et al., 2011). While these data are promising, the findings may not extrapolate to other populations, including middle-aged adults, as the sleep needs of participants (≈ 6 - 11 h) in these previous studies are likely greater than middle-aged adults (≈ 6 - 10 h) (Hirshkowitz et al., 2015). As such, the exploration of the effects of EXT on mood states in older adults may be needed to determine whether an increase in sleep duration can alleviate negative mood and stress.
Table 2.2 Previous literature on the effects of sleep loss on mood states and wellness.

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Sleep Intervention</th>
<th>Mood State Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Profile of Mood States</td>
</tr>
<tr>
<td><strong>Total Sleep Deprivation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meney et al. (1998)</td>
<td>n = 11 men</td>
<td>CONT (normal sleep, 1 night)</td>
<td>TENSION NSD</td>
</tr>
<tr>
<td></td>
<td>25 y</td>
<td>TSD (1 night)</td>
<td>DEPRESSION NSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ANGER↓ TSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>VIGOR↑ TSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FATIGUE↑ TSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CONFUSION↑ TSD</td>
</tr>
<tr>
<td>Scott et al. (2006)</td>
<td>n = 6 men</td>
<td>BASE</td>
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<td>VIGOUR↓ TSD</td>
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<td>Selvi et al. (2007)</td>
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<td>RES-M (3.5 h, 1 night)</td>
<td>ANGER ↓ RES-E</td>
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<td>n = 30 M chronotypes (10 women)</td>
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<td>VIGOUR ↓ TSD-M, TSD-E, RES-E</td>
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<td>FATIGUE ↑ TSD-M; RES-E</td>
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<td>n = 30 E chronotypes (10 women)</td>
<td>TMD</td>
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<td>Ikegami et al. (2009)</td>
<td>n = 10 men</td>
<td>BASE (7 h, 1 night)</td>
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<td>22 y</td>
<td>TSD (41 h)</td>
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<td>REC (7 h, 3 nights)</td>
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<td>Paterson et al. (2011)</td>
<td>62 adults</td>
<td>22 y</td>
<td>BASE (normal sleep, 1 night) TSD-1 (39 - 42 h) TSD-2 (63 - 66 h)</td>
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<tr>
<td>Skein et al. (2011)</td>
<td>10 male athletes</td>
<td>21 y</td>
<td>CONT (normal sleep, 1 night) TSD (30 h)</td>
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<td>van Heugten–van der Kloet et al. (2015)</td>
<td>56 students (43 women)</td>
<td>21 y</td>
<td>CONT (n = 28, normal sleep) TSD (n = 28, 36 h)</td>
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<td>Sleep Restriction</td>
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<tr>
<td>Dinges et al. (1997)</td>
<td>16 adults</td>
<td>23 y</td>
<td>CONT (normal sleep, 7 nights) RES (50 % of normal sleep, 7 nights)</td>
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<tr>
<td>Ablin et al. (2013)</td>
<td>87 adults</td>
<td>27 y</td>
<td>CONT (normal sleep and exercise, 10 days) RES (6 h, 10 days) EX DEP (no running, 10 days) RES and EX DEP (6 h, no running, 10 days)</td>
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<td>Sleep Fragmentation</td>
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<tr>
<td>Bonnet et al. (1991)</td>
<td>12 men</td>
<td>18 - 28 y</td>
<td>BASE (normal sleep, 1 night) FRAG (several awakenings, 1 night) REC (normal sleep, 1 night)</td>
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<tr>
<td>Gonnissen et al. (2013)</td>
<td>12 men</td>
<td>23 y</td>
<td>CONT (8 h, 1 night) FRAG (8 h, alarms every 90 min, 1 night)</td>
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</table>
### Chapter 2: Literature Review

<table>
<thead>
<tr>
<th>Study</th>
<th>n =</th>
<th>Type of Participants</th>
<th>Baseline Sleep</th>
<th>Experimental Conditions</th>
<th>Measures</th>
<th>Results</th>
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<tbody>
<tr>
<td>Kahn et al. (2014)</td>
<td>61</td>
<td>students (40 women)</td>
<td>61, normal sleep, 1 night</td>
<td>CON (n = 61), FRAG (n = 31, 8 h, alarms every 90 min, 1 night), RES (n = 30, 4 h, 1 night)</td>
<td>ANGER, CONFUSION, DEPRESSION, FATIGUE, TENSION, VIGOUR</td>
<td>↑ NSD; ↑ FRAG; RES; ↑ FRAG; RES; ↑ FRAG; RES; ↑ NSD</td>
</tr>
<tr>
<td>Finan et al. (2015)</td>
<td>62</td>
<td>adults (41 women)</td>
<td>24, uninterrupted sleep, 3 nights</td>
<td>CON (n = 24), FRAG (n = 21, awakenings every 1 h, 3 nights), RES (n = 17, ≈ 3.5 h, 3 nights)</td>
<td>POSITIVE MOOD, NEGATIVE MOOD</td>
<td>↓ FRAG &gt; RES; ↑ FRAG &gt; RES</td>
</tr>
<tr>
<td>Kamdar et al. (2004)</td>
<td>15</td>
<td>students (4 women)</td>
<td>6 - 9 h, 5 nights</td>
<td>BASE (6 - 9 h, 5 nights), EXT (as much as possible, ≤ 48 nights)</td>
<td>VIGOUR, FATIGUE</td>
<td>↑ EXT; ↓ EXT</td>
</tr>
<tr>
<td>Mah et al. (2011)</td>
<td>11</td>
<td>male athletes</td>
<td>6.5 h, nights varied</td>
<td>BASE (6.5 h, nights varied), EXT (8.5 h, 5 - 7 weeks)</td>
<td>VIGOUR, FATIGUE, TENSION, DEPRESSION, ANGER, CONFUSION, TMD</td>
<td>↑ EXT; ↓ EXT; ↓ EXT; ↓ EXT; ↓ EXT; ↓ EXT</td>
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</table>

APO: approximately; BASE: baseline sleep; BMI: body mass index; CONT: control/normal sleep; ↓: decrease; DEP: deprivation; E: evening; EX: exercise; EXT: sleep extension; FRAG: sleep fragmentation; >: greater than; h: hours; ↑: increase; kg·m²: kilograms per metre squared; ≤: less than or equal to; min: minutes; M: morning; n: number of participants; NSD: no significant difference; %: percent; REC: sleep recovery; RES: sleep restriction; TMD: total mood disturbance; TSD: total sleep deprivation; y: years.
2.6 Exercise and Sleep

While regular exercise is broadly accepted as an important behaviour for aiding sleep duration and perceived sleep quality (Kredlow et al., 2015; Urponen et al., 1988; Yang et al., 2012), there is continued debate regarding optimal exercise intensities and time-of-day to exercise (Flausino et al., 2012; Hayashi et al., 2014; Passos et al., 2010; Robey et al., 2013; Roveda et al., 2011; Souissi et al., 2012). Early research suggested that higher exercise intensities were more important than the total volume of energy expended for changing subsequent sleep (Horne, 1981). Regardless, much of the research thus far has presented modest and varying robustness in sleep changes following exercise, regardless of intensity (Kredlow et al., 2015). Moreover, the avoidance of HIE close to bedtime remains to be a recommendation for sleep promotion (AASM, 2001) despite growing evidence which suggests that sleep disruption is unlikely to occur following evening HIE (Dworak et al., 2008; Flausino et al., 2012; Hayashi et al., 2014; Irish et al., 2015; Robey et al., 2013). Instead, several mechanisms have been postulated regarding why HIE may stimulate greater needs for deeper sleep, which some would suggest is a beneficial response (Netzer et al., 2001; Tasali, Leproult, Ehrmann, & Van Cauter, 2008).

The physiological strain of HIE is considered much greater compared to that induced by MICE; whereby a higher magnitude of change in heart rate, release of metabolic hormones, build-up of lactate and depletion of metabolite substrates occur (Boutcher, 2010). As such, it is plausible that this response may extend time of recovery and further stimulate the need for greater restorative sleep (SWS), particularly in the first half of sleep, when HIE is performed later in the day (Robey et al., 2013). The substantial increase in norepinephrine after HIE may also contribute to greater proportions of stage N3 sleep due to its effects on enhancing long-term potentiation which only occurs in NREM sleep stages (Netzer et al., 2001; Poe, Walsh, & Bjorness, 2010). Sections 2.6.1 and 2.6.2 will explore the current literature which has investigated the effects of acute HIE/HIIE and MICE, and exercise time-of-day on subsequent sleep in relation to the potential mechanisms which continue to be pondered. This literature review will further highlight that research has predominantly focused on young adults and ‘good sleepers’. Therefore, results
may not appropriately reflect potential sleep responses to exercise of differing intensities or times of day for older adults likely to be experiencing some sleep complications (Adams et al., 2017).

### 2.6.1 The effect of exercise intensity on sleep characteristics

Exercise is believed to induce favourable changes in sleep duration and quality (TST, stage N3 sleep, SOL); but, experimental evidence suggests that these changes are small and transient (Kredlow et al., 2015; Youngstedt, 2005). As such, there is a continual debate regarding the optimal exercise intensity (particularly HIIE vs MICE) for inducing the most beneficial effects on sleep (Table 2.3). In an early review regarding this topic, Horne (1981) argued that the performance of HIE, rather than the act of expending a large volume of energy, is required to alter subsequent sleep. Findings from Dworak et al. (2008) support this notion as authors observed a significant increase in SE and stage N3 sleep, and decrease in SOL following a HIE cycling protocol (85 - 90 % HR\text{max} to exhaustion) compared to MICE (65 - 70 % HR\text{max}, 30 min) within a young male cohort (13 ± 1 y, BMI: 18 ± 2 kg·m\(^2\)). Flausino et al. (2012) and Hayashi et al. (2014) have also reported an increase in SE and SOL following HIE protocols compared to BASE for men (23 - 27 y, BMI: 22 - 25 kg·m\(^2\)); however, these findings were not significantly different to MICE effects. Conversely, 12 insomnia patients (44 ± 8 y, BMI: 25 ± 4 kg·m\(^2\)) experienced sleep improvements, including TST (+ 18 %), SE (+ 13 %) and SOL (- 55 %) following 50 min of moderate-intensity aerobic exercise [running at ventilatory threshold (VT) 1] compared to patients who completed a non-exercise CONT (\(n = 12\)), HIE (\(n = 12\), VT2, 3 × 10 min walk: 10 min rest) and moderate-intensity resistance exercise [\(n = 12\), 50 % of 1 repetition maximum (RM), whole-body; ≈ 50 min] (Passos et al., 2010). Given the differences between results and participants recruited by these studies, it is apparent that age and clinical sleep status plays an important role in sleep responses to differing exercise intensities.

When considering a large proportion of the current literature, there has been a prominent focus on individuals classified as ‘good sleepers’ who obtain recommended sleep and have no sleep complaints.
Youngstedt (2005) has previously remarked that good sleepers are unlikely to demonstrate large improvements in sleep following exercise of any intensity compared to a non-exercise CONT due to a reduced need to obtain more TST or improve sleep quality. This idea was demonstrated by Rossi et al. (2010) who examined PSG recorded sleep in 102 men ($n = 40$) and women ($n = 62$) aged $28 \pm 7$ y, inactive and classified as good sleepers to complete either MICE ($n = 19$, 60% $\dot{V}O_{peak}$, 30 min), HIIE ($n = 13$, 140% MET load, $10 \times 35$ s:4 min), or a resistance session ($n = 70$, 50% 1RM, 6 exercises, 3 x 15). The authors compared the differences between BASE sleep and sleep following each respective exercise trial, revealing no significant sleep changes (SOL: $p = 0.09 - 0.60$, stage N3 sleep: $p = 0.60 - 0.46$, SE: $p = 0.10 - 0.88$) (Rossi et al., 2010). Given the study design (between-group), authors were restricted in that results from each exercise trial could be compared back to BASE only and not the exercise trials as participants only completed one exercise intervention. When solely considering the mean sleep data by Rossi et al. (2010) there were moderate - large sleep differences between the exercise trials, such as REM latency (MICE: $78 \pm 28$ min, HIIE: $104 \pm 60$ min, resistance: $95 \pm 39$ min), SE (MICE: $88 \pm 9$ %, HIIE: $89 \pm 8$ %, resistance: $91 \pm 6$ %), and stage N3 sleep (MICE: $21 \pm 6$ %, HIIE: $25 \pm 6$ %, resistance: $25 \pm 12$ %) which may have provided further understanding of optimal exercise intensity (MICE vs HIIE) and exercise mode (aerobic vs resistance) for sleep.

A further limitation of the current literature, which has explored exercise intensity and sleep, is the substantial recruitment of adults who not only have minimal sleep complaints but also aged $\leq 30$ y (Table 2.3). As previously outlined, there are age-related changes in sleep, including reduced TST and stage N3 sleep, that tends to occur from 35 y of age (Alves et al., 2011; Copinschi et al., 2014). Moreover, the prevalence of sleep complaints and disorders tend to increase with age, particularly among men, with some studies reporting up to 30 - 40 % of men (40 - 60 y) are diagnosed with OSA (Heinzer et al., 2015; Tufik, Santos-Silva, Taddei, & Bittencourt, 2010). As such, it may not be unreasonable to assume that sleep...
responses to exercise of differing intensities (e.g. MICE vs HIIE) may be different for middle-aged adults compared to their younger counterparts, particularly when the physiological stress of HIIE and fitness level of individuals are considered. In concern to HIIE, there is a more rapid increases in heart rate, release of metabolic hormones (e.g. GH), lactate, and depletion of adenosine triphosphate, creatine phosphate and glycogen stores compared to MICE (Boutcher, 2010; Tomlin & Wenger, 2001; Trapp, Chisholm, & Boutcher, 2007; Weinstein, Bediz, Dotan, & Falk, 1998). There is some evidence to suggest that this greater physiological strain may extend the duration of recovery and elevation in oxygen consumption after exercise to support the return of metabolic processes to a resting state (Boutcher, 2010; Laforgia, Withers, & Gore, 2006). Additionally, fitness level or ‘training status’ has been shown to have differing effects on recovery durations, such that untrained individuals tend to experience slower rates of recovery compared to trained individuals (Børsheim & Bahr, 2003; Gore & Withers, 1990). Therefore, it is plausible that middle-aged adults (35 - 60 y) who do not engage in regular exercise and/or may be experiencing negative age-related sleep changes would benefit from HIIE whereby a greater need for tissue repair and growth is required, and deeper restorative sleep may be stimulated. However, conclusions and recommendations may not yet be drawn given the limited data regarding sleep and exercise intensity specific to middle-aged cohorts.
<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Exercise Intensity</th>
<th>Polysomnography</th>
<th>Sleep Measures</th>
<th>Actigraphy</th>
<th>Sleep Diaries</th>
<th>Questionnaires</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunnell et al. (1983)</td>
<td>n = 9 adults (5 women) 27 (24) y</td>
<td>EX (1 h: 50 % VO_{2max} + 1 h: 60 % VO_{2max} + 1 h: 70 % VO_{2max} ± 70 % VO_{2max} to volitional exhaustion)</td>
<td>TST</td>
<td>NSD</td>
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<td>SOL</td>
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<td>N3 sleep</td>
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<td>Dworak et al. (2008)</td>
<td>n = 11 boys 13 y BMI 18 kg·m²</td>
<td>MICE (65 - 70 % H_{R \text{max}}, 30 min)</td>
<td>TST</td>
<td>NSD</td>
<td>↑ HIE</td>
<td>↓ HIE</td>
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<td>SE</td>
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<tr>
<td>Passos et al. (2010)</td>
<td>n = 48 insomnia patients (38 women)</td>
<td>CONT (n = 12, no exercise) MICE (n = 12, VT1, 50 min) HIE (n = 12, VT2, 3 x 10 min walk: 10 min rest) RES (n = 12, 50 % of 1RM, WB; = 50 min)</td>
<td>TST</td>
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<td>BMI 25 kg·m²</td>
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<td>SOL</td>
<td>↓ MICE</td>
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<td>REM latency</td>
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<td>Age</td>
<td>BMI</td>
<td>Interventions</td>
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<tr>
<td>Rossi et al. (2010)</td>
<td>n = 102 adults (62 women)</td>
<td>29 y</td>
<td>24 kg·m²</td>
<td>HIIE (n = 13, 140 % MET load, 10 × 35 s: 4 min) MICE (n = 19, 60 % VO₂peak, 30 min) RES (n = 70, 50 % 1RM, WB: 3 × 15)</td>
<td>TST NSD SE NSD SOL NSD REM latency NSD N1 sleep NSD N2 sleep NSD N3 sleep NSD REM sleep NSD Total arousals NSD</td>
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<td>Flausino et al. (2012)</td>
<td>n = 18 men</td>
<td>27 y</td>
<td>25 kg·m²</td>
<td>MICE-30 (VT1, 30 min) MICE-60 (VT1, 60 min) HIE-30 (50 % above VT1, 30 min) HIE-60 (50 % above VT1, 60 min)</td>
<td>TST NSD SE ↑ All trials SOL NSD REM latency ↓ MICE-60 WASO ↓ All trials N1 sleep ↓ MICE-30, HIE-30, HIE-60 N2 sleep NSD N3 sleep NSD REM sleep NSD</td>
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<td>Myllymäki et al. (2012)</td>
<td>n = 14 active men</td>
<td>36 y</td>
<td>24 kg·m²</td>
<td>CONT (no exercise, 30 min) LIE (45 %, 30 min) MICE (60 %, 30 min) HIE (75 %, 30 min)</td>
<td>TIB NSD TST NSD SE NSD Activity Score NSD</td>
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<tr>
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<tr>
<td>Wong et al.</td>
<td>n = 12 adults (9 women) 25 y BMI 23 kg·m²</td>
<td>LIE (45 % VO₂max, 40 min) MICE-1 (55 % VO₂max, 40 min) MICE-2 (65 % VO₂max, 40 min) HIE (75 % VO₂max, 40 min)</td>
<td></td>
<td>TST SE SOL REM latency WASO N1 &amp; N2 sleep N3 sleep REM sleep</td>
<td>↑ MICE-2, HIE</td>
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<tr>
<td>Hayashi et al.</td>
<td>n = 9 men 23 y BMI 22 kg·m²</td>
<td>LIE (50 % HRmax, 1 h) MICE (60 % HRmax, 1 h) HIE (80 % HRmax, 1 h)</td>
<td></td>
<td>TIB TST SE SOL REM latency WASO N1 sleep N2 sleep N3 sleep REM sleep</td>
<td>↓ MICE, HIE</td>
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</table>

*: approximately; 1RM: one repetition-max; BMI: body mass index; CONT: no exercise trial; ↓: decrease; EX: exercise; HIE: high-intensity exercise; HIE: high-intensity interval exercise; h: hours; HRmax: maximum heart rate; ↑: increase; kg·m²: kilograms per metre squared; LIE: low-intensity exercise; MET: metabolic equivalents; min: minutes; MICE: moderate-intensity continuous exercise; ×: multiply; N1: stage N1 sleep; N2: stage N2 sleep, N3: stage N3 sleep; n: number of participants; NSD: no significant difference; %: percent; PSQI: Pittsburgh Sleep Quality Index; +: plus; ±: plus-minus sign; REM: rapid eye movement; RES: resistance exercise; s: seconds; SE: sleep efficiency; SOL: sleep onset latency; TIB: time in bed; TST: total sleep time; VO₂max: maximal oxygen consumption; VO₂peak: peak oxygen consumption; VT1: ventilatory threshold one; VT2: ventilatory threshold two; WASO: wake after sleep onset; WB: whole-body; y: years.
2.6.2 The effect of exercise time-of-day on sleep characteristics

Adults are encouraged to participate in regular exercise to promote sleep improvements, such as increase sleep duration and sleep continuity (Buman et al., 2014). Nonetheless, there has been a reduction in both exercise participation and sleep duration, which is reportedly due to ‘lacking time’ (Buman et al., 2014; Gibala et al., 2012; Rajaratnam & Arendt, 2001). In Australia, peak physical inactivity tends to occur between 35 - 54 y of age (ABS, 2015) which coincides with a large percentage (60 - 64 %) of this age group experiencing one persistent sleep problem, such as not obtaining adequate sleep or waking frequently during the night (Adams et al., 2017). While short-duration, HIIE has been promoted has a possible alternative to longer duration MICE (Gibala & McGee, 2008), the AASM (2001) tend to advise the avoidance of vigorous exercise close to bedtime due to increased arousal which may extend SOL and disrupt sleep continuity. Therefore, discouraging evening HIIE and promoting the notion that exercise should be performed within 4 - 8 h prior to bedtime may remove a preferential time-of-day for exercise or eliminate exercise participation altogether for time-poor individuals (Buman et al., 2014; Youngstedt, 2005). However, more recent experimental evidence suggests that evening HIE/HIIE may not disturb subsequent sleep, particularly among active, young adults (19 - 29 y) (Table 2.4).

Much of the research investigating the effects of evening exercise on sleep have compared different exercise modes, or exercise compared to non-exercise CONT (Browman & Tepas, 1976; Flausino et al., 2012; Hayashi et al., 2014; Myllymäki et al., 2011; Oda & Shirakawa, 2014; Robey et al., 2013; Roveda et al., 2011) rather than the same exercise protocol performed across different times of the day. In an early investigation, nine men (19 y) participated in three separate trials involving 45 min of i) relaxation (REX: tension/relaxation technique of muscle groups), ii) vigilance (VIG: task to identify short tone), and iii) exercise (5 min self-paced cycling: 3 min passive rest) performed 50 min prior to bedtime (Browman & Tepas, 1976). The authors reported that there were no significant sleep differences between the three trials, except for REM latency which was delayed following the exercise trial (Browman & Tepas, 1976).
Since then, Myllymäki et al. (2011) and Robey et al. (2013) conducted studies which compared subsequent sleep responses to a HIE protocol and a non-exercise CONT. Myllymäki et al. (2011) recruited 11 active adults (26 ± 3 y) to complete either CONT (no exercise) or HIE (≈ 35 min, 3 min stages of increasing power, initial power output for women: 25 W, for men: 100 W) at 2100 h. Again, there were only minor sleep changes with a significant increase in NREM sleep following evening HIE (74 ± 5 %) compared to CONT (69 ± 4 %) (Myllymäki et al., 2011). There was also a slight decrease in REM sleep following HIE (18 ± 4 %) compared to CONT (21 ± 7 %); however, this difference was not significant (Myllymäki et al., 2011). In a similar study, 11 male cyclists (26 ± 4 y) performed three separate trials, including i) CONT (40 min, quiet sitting), HIE (15 min at 75 % peak power, 5 min rest, 15 min maximal time trial), and iii) HIE with cold water immersion (exercise protocol followed by 15 min in 14 °C water) (Robey et al., 2013). While authors did not observe significant differences between trials for whole night PSG recorded sleep, there was a significant increase in NREM sleep (+ 4 %) and decrease in REM sleep (- 5 %) in the initial 180 min of sleep following HIE (Robey et al., 2013). A possible mechanism for these sleep observations was proposed by Netzer et al. (2001) who reported a strong correlation between an extension of REM onset latency and reduction of the proportion of REM sleep during the first half of sleep with an increase in norepinephrine following HIE. Although this is yet to be fully elucidated, it is known that noradrenergic cells are tonically active during all sleep stages except for REM sleep (Poe et al., 2010) and, compared to MICE, HIE is associated with a post-exercise 14.5 fold increase in norepinephrine release (Boutcher, 2010). Moreover, norepinephrine has been shown to enhance and prolong long-term potentiation (persistent strengthening of synapses based on recent patterns of activity) which occurs during NREM sleep (Poe et al., 2010). As such, it is plausible to assume that the presence of higher norepinephrine prior to bedtime, which is likely induced by HIE, may be linked to delayed REM sleep and the enhancement of NREM sleep during the first half of the night.
Two studies have investigated sleep responses to the same exercise protocol performed at different times of day (Alley et al., 2015; Souissi et al., 2012). Firstly, 24 college students (20 y) were recruited to perform a whole-body resistance session involving three sets of ten repetitions of various upper and lower body exercises on three separate occasions (MORN: 0700 h, AFT: 1300 h, EVEN: 1900 h) with sleep variables recorded via an ambulatory wireless sleep-monitoring headband (Alley et al., 2015). Key findings of this study revealed that participants experienced a shorter SOL following MORN (36 ± 5 min) compared to AFT (57 ± 7 min) and EVEN (71 ± 13 min) trials; however, there was a significant decrease in WASO following EVEN (5 ± 1 min) compared to CONT (16 ± 4 min) (Alley et al., 2015). Nonetheless, regardless of time-of-day, authors reported that participation in resistance exercise resulted in fewer number of awakenings (2 - 3) compared to CONT (4) (Alley et al., 2015). These results suggest that while AFT and EVEN resistance exercise may delay SOL, sleep continuity may be improved (reduced number of awakenings). However, a study by Souissi et al. (2012) has shown that the performance of HIIE, which may be of similar or higher intensity to resistance exercise, may be detrimental for sleep when performed in the evening. 12 trained participants (23 ± 2 y, BMI: 22 kg·m²) were recruited to perform the Yo-Yo intermittent recovery test - level one during two separate trials, including AFT (1400 h) and EVEN (2000 h) (Souissi et al., 2012). Following EVEN, there was a decrease in TIB (EVEN: 483 min, AFT: 507 min), TST (EVEN: 383 min, AFT: 445 min), SE (EVEN: 80 %, AFT: 88 %) and REM sleep (EVEN: 10 min AFT: 17 min), and an increase in SOL (EVEN: 29 min, AFT: 21 min), REM latency (EVEN: 204 min, AFT: 155 min), stage N1 sleep (EVEN: 5.1 %, AFT: 4 %) and SWS (EVEN: 14 %, AFT: 12 %) compared to AFT (Souissi et al., 2012). Although an increase in SWS in isolation would suggest an improvement in sleep given the restorative functions associated with this sleep stage (Paterson, 2012), the overall sleep changes following evening HIIE reported by Souissi et al. (2012) indicates a negative impact on sleep compared to HIIE performed in the early parts of the day.

Researchers have proposed that body temperature and melatonin may play a critical role in evening exercise-induced sleep changes (Lack & Wright, 2007; Souissi et al., 2012). In relation to sleep, melatonin
has been shown to precede sleep onset by 2 h (≈ 2100 h), peak between 0100 - 0300 h before progressively declining to barely detectable ranges from 0900 h (Lack & Wright, 2007). However, Van Reeth et al. (1994) showed a delay in the nocturnal rise of melatonin by 1 - 2 h following evening exercise (3 h, 36 min cycles, 60 % VO$_{2peak}$; 40 % VO$_{2peak}$); while similar findings have also been reported by Buxton et al. (1997) and Baehr et al. (2003). These results suggest there may be a direct link between exercise-induced decreases in melatonin and delayed SOL. However, more recent evidence suggests that the reduction in melatonin following evening exercise may actually be a by-product of a delay in the timing of the body clock (Youngstedt et al., 2016; Youngstedt et al., 2019). Nevertheless, these findings may be somewhat inadmissible for many time-poor individuals given that these studies implemented 1 - 3 h exercise protocols. As for the circadian patterns of body temperature, research has indicated peak temperature is reached in the early evening before decreasing towards a nadir which occurs between 0300 - 0600 h, with wake time ensuing a short time after (Lack & Wright, 2007). In addition, further evidence indicates that a rise in core body temperature prior to sleep onset leads to increased sleepiness and sleep propensity due to a subsequent need for temperature dissipation via cutaneous vasodilation (Kräuchi, 2007; Kräuchi et al., 2018). Previous studies have shown that rises in body temperature following exercise in the evening may induce this thermoregulatory effect on sleep and aids in increasing SWS duration (Atkinson & Davenne, 2007; Horne & Moore, 1985; Horne & Staff, 1983; O’Connor, Breus, & Youngstedt, 1998). For example, Horne and Staff (1983) recruited eight active participants (25 ± 4 y) who completed three separate trials between 1400 h and 1800 h, including i) HIE (2 × 40 min, 80 % VO$_{2max}$), ii) CONT in the heat (seated in warm water: 42 °C), and iii) low-intensity exercise (LIE: 2 × 80 min, 40 % VO$_{2max}$). The authors reported that there was an increase in SWS following HIE (89 ± 22 min) and CONT in the heat (94 ± 16 min), while there was no significant increase following LIE (75 ± 23 min) compared to BASE (76 ± 17 min) (Horne & Staff, 1983). Albeit, criticism of this study and others (Horne & Moore, 1985; O’Connor et al., 1998) have occurred due to the emphasis on the amount of SWS as an indicator of sleep quality (Atkinson & Davenne, 2007). Given that disparity continues to arise from evening HIE investigations, it is evident that further research is required to explore i) the viability of evening short-
duration, HIIE for time-restrained individuals instead of prolonged exercise protocols, and ii) whether short-duration, HIIE is an appropriate option for currently inactive populations without inducing deleterious sleep responses.
Table 2.4 Previous literature investigating the effect of exercise time-of-day on sleep characteristics.

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Exercise Time-of-Day</th>
<th>Polysomnography</th>
<th>Sleep Measures</th>
<th>Sleep Diaries &amp; Questionnaires</th>
</tr>
</thead>
<tbody>
<tr>
<td>Browman and Tepas (1976)</td>
<td>n = 9 men 19 y</td>
<td>REX (50 min prior to bedtime) VIG (50 min prior to bedtime) EVEN (50 min prior to bedtime)</td>
<td>TST NSD</td>
<td>NSD</td>
<td>↑ EVEN</td>
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<tr>
<td>O'Connor et al. (1998)</td>
<td>n = 8 men 21 y</td>
<td>CONT (90 min prior to bedtime) EVEN-LIE (90 min prior to bedtime) EVEN-MICE (90 min prior to bedtime)</td>
<td>TST NSD SE NSD SOL NSD Awakenings NSD</td>
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<tr>
<td>Myllymäki et al. (2011)</td>
<td>n = 11 active adults (4 women) 26 y</td>
<td>CONT EVEN (2100 h)</td>
<td>TIB TST NSD SOL NSD N1 sleep NSD N2 sleep NSD N3 sleep NSD NREM sleep NSD REM sleep ↑ EVEN</td>
<td>TST SE NSD SQ NSD</td>
<td></td>
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<tr>
<td>Roveda et al. (2011)</td>
<td>n = 15 men 29 y BMI 25 kg·m⁻²</td>
<td>EVEN-HIE (2200 h) EVEN-RES (2200 h)</td>
<td>TIB ↑Both trials TST ↑Both trials SE ↑EVEN-HIE SOL ↓EVEN-RES</td>
<td></td>
<td></td>
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<tr>
<td>Author(s)</td>
<td>n = 18 men</td>
<td>EVEN-MICE30 (2000 h)</td>
<td>TST</td>
<td>NSD</td>
<td>PSQI</td>
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<tr>
<td>Flausino et al.</td>
<td>27 y</td>
<td>EVEMICE60 (2000 h)</td>
<td>SE</td>
<td>↑ All trials</td>
<td>4.6 (good)</td>
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<td></td>
<td>BMI 25 kg·m²</td>
<td>EVEN-HIE30 (2000 h)</td>
<td>SOL</td>
<td>NSD</td>
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<td></td>
<td></td>
<td>EVEN-HIE60 (2000 h)</td>
<td>REM latency</td>
<td>↓ EVEN-MICE60</td>
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<td>WASO</td>
<td>↓ All trials</td>
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<td>N1 sleep</td>
<td>↓ EVEN-MICE30, EVEN-HIE30, EVEN-HIE60</td>
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<td>N2 sleep</td>
<td>NSD</td>
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<td>N3 sleep</td>
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<td>REM sleep</td>
<td>NSD</td>
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<table>
<thead>
<tr>
<th>Author(s)</th>
<th>n = 12 trained participants</th>
<th>EVEN (2000 h)</th>
<th>TIB</th>
<th>↓ EVEN</th>
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<tbody>
<tr>
<td>Souissi et al.</td>
<td>23 y</td>
<td>AFT (1400 h)</td>
<td>TST</td>
<td>↓ EVEN</td>
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<td></td>
<td>BMI 22 kg·m²</td>
<td>EVEN (2000 h)</td>
<td>SE</td>
<td>↓ EVEN</td>
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<td>SOL</td>
<td>↑ EVEN</td>
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<td>REM latency</td>
<td>↑ EVEN</td>
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<td>N1 sleep</td>
<td>↑ EVEN</td>
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<td>N2 sleep</td>
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<td>SWS</td>
<td>↑ EVEN</td>
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<td>REM sleep</td>
<td>↓ EVEN</td>
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<table>
<thead>
<tr>
<th>Author(s)</th>
<th>n = 11 male cyclists</th>
<th>CONT</th>
<th>Whole-night:</th>
<th>NSD</th>
<th>Compared to home:</th>
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<td>Robey et al.</td>
<td>26 y</td>
<td>EVEN-EX (1830 h)</td>
<td>TST</td>
<td>NSD</td>
<td>TST</td>
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<td></td>
<td></td>
<td>EVEN-CWI (1830 h)</td>
<td>SE</td>
<td>NSD</td>
<td>↑ CON</td>
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<td>SOL</td>
<td>↓ CON, EVEN-CWI</td>
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<td>WASO</td>
<td>↓ CON</td>
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<tr>
<td>Study</td>
<td>Participants</td>
<td>Time Points</td>
<td>Conditions</td>
<td>Measures</td>
<td>Results</td>
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<tr>
<td>Hayashi et al. (2014)</td>
<td>n = 9 men</td>
<td>CONT</td>
<td>EVEN-LIE</td>
<td>TIB</td>
<td>NSD</td>
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<tr>
<td></td>
<td>23 y</td>
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<td>EVEN-MICE</td>
<td>TST</td>
<td>NSD</td>
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<td>BMI 22 kg·m^2</td>
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<td>EVEN-HIE</td>
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<td>SOL</td>
<td>↓ EVEN-MICE, EVEN-HIE</td>
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<td>REM latency</td>
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<tr>
<td>Oda and Shirakawa (2014)</td>
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<td>TST</td>
<td>NSD</td>
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<tr>
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<td>SE</td>
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<td>(2120 h)</td>
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<td>REM latency</td>
<td>NSD</td>
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<td>WASO</td>
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<tr>
<td>Alley et al. (2015)</td>
<td>n = 24 students</td>
<td>MORN</td>
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<td>NSD</td>
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<td>(0700 h)</td>
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<td>REM</td>
<td>NSD</td>
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<td>↓ MORN</td>
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<td>WASO</td>
<td>↓ EVEN</td>
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<td></td>
<td></td>
<td>NREM</td>
<td>↓ All trials</td>
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**AFT:** afternoon exercise; **BMI:** body mass index; **CONT:** no exercise trial; **CWI:** cold water immersion; ↓: decrease; **EVEN:** evening exercise; **EX:** exercise; **HIE:** high-intensity exercise; **h:** hours; ↑: increase; **kg·m^2:** kilograms per metre squared; **LIE:** low-intensity exercise; **MICE:** moderate-intensity continuous exercise; **min:** minutes; **MORN:** morning exercise; **N1:** stage N1 sleep; **N2:** stage N2 sleep; **N3:** stage N3 sleep; **n:** number of participants; **NREM:** non-rapid eye movement; **NSD:** no significant difference; **PSQI:** Pittsburgh Sleep Quality Index; **REM:** rapid eye movement; **RES:** resistance exercise; **REX:** relaxation; **SE:** sleep efficiency; **SOL:** sleep onset latency; **SQ:** sleep quality; **SWS:** slow wave sleep; **TIB:** time in bed; **TST:** total sleep time; **VIG:** vigilance; **WASO:** wake after sleep onset; **y:** years.
2.7 Exercise and Appetite Regulation

2.7.1 The effects of exercise intensity on appetite regulation and control

Exercise has been shown to improve appetite regulation by suppressing orexigenic signals, stimulating anorexigenic signals and enhancing sensitivity to these signals (Dyck, 2005; Martins et al., 2008). However, the effect of exercise on appetite hormone responses varies depending on exercise mode, intensity and duration of exercise (Balaguera-Cortes et al., 2011; Broom et al., 2009; Broom et al., 2017; Sim et al., 2014). Previous literature has predominantly explored differences in the effects of traditional MICE and resistance exercise on appetite regulation given that these types of exercise represent two opposing, yet regularly engaged modes of exercise, with differing molecular adaptation pathways (Balaguera-Cortes et al., 2011; Broom et al., 2009; Guelfi, Donges, & Duffield, 2013). There appears to be a consensus in which MICE induces prolonged suppression of hunger due to reductions in acylated ghrelin and increases in anorexigenic hormones, such as PYY$_{\text{total}}$, pancreatic polypeptide (PP) and glucagon-like peptide-1 (GLP-1) (Balaguera-Cortes et al., 2011; Heden et al., 2013b; Rosenkilde et al., 2013). Appetite-related responses following resistance exercise have been variable, with some studies indicating that there is a transient suppression of hunger (Broom et al., 2009; Deighton et al., 2013), while other studies have reported an increase in perceived hunger and energy intake (Cadieux et al., 2014). Similarly, there is ongoing interest regarding the optimal exercise intensity for inducing the most beneficial appetite responses, particularly for aerobic-based exercise.

Growing evidence suggests that HIE/HIIE, compared to MICE, likely induces greater reductions in orexigenic signals, prolongs hunger suppression and reduces energy intake for up to 24 h post-exercise (Broom et al., 2017; Holliday & Blannin, 2017; Howe, Hand, & Manore, 2014; Martins et al., 2015; Panissa et al., 2016; Sim et al., 2014; Thivel et al., 2012). For instance, nine men (21 ± 2 y, BMI: 25 ± 2 kg·m$^2$) completed three experimental trials, including CONT (rested), MICE (≈ 55 min, 50 % VO$_{2\text{peak}}$, gross energy expenditure of 2 510 kJ) and HIE (≈ 36 min, 75 % VO$_{2\text{peak}}$, gross energy expenditure of 2 510 kJ) (Broom et
The authors reported that despite matching energy expenditure for both exercise trials, HIE significantly reduced acylated ghrelin (Δ change: \(-17.8 \pm 19.2 \text{ pg·mL}^{-1}\)) for up to 4 h after exercise compared to MICE (Δ change: \(-6.8 \pm 11.8 \text{ pg·mL}^{-1}\)) and CONT (Δ change: \(2.3 \pm 8.2 \text{ pg·mL}^{-1}\)) (Broom et al., 2017). Although the study by Broom et al. (2017) demonstrates a favourable reduction in orexigenic signals post-HIE, it is perhaps unlikely for overweight or obese individuals to maintain an exercise intensity of ≥ 75 % \(\dot{V}O_{2}\text{peak}\) continuously for an extended time due to differences in training status and differing dependency on macronutrients during various exercise intensities (Perez-Martin et al., 2001). Instead, Sim et al. (2014) conducted a study involving 17 overweight, inactive men (30 ± 8 y, BMI: 28 ± 2 kg·m\(^{-2}\)) who completed four separate trials, including a i) CONT (supine rest, 30 min), ii) MICE (60 % \(\dot{V}O_{2}\text{peak}\), 30 min), iii) HIIE (60 s at 100 % \(\dot{V}O_{2}\text{peak}\): 240 s at 50 % \(\dot{V}O_{2}\text{peak}\), 30 min) and iv) very HIIE (15 s at 170 % \(\dot{V}O_{2}\text{peak}\): 60 s at 32 % \(\dot{V}O_{2}\text{peak}\)). Like Broom et al. (2017), significant declines in acylated ghrelin were observed post-exercise for very HIIE compared to HIIE, MICE and CONT (\(p \leq 0.05\)); while, glucose was significantly higher following very HIIE compared to all other trials (\(p \leq 0.02\)) (Sim et al., 2014). Sim et al. (2014) further reported that HIIE (2 602 kJ) and very HIIE (2 488 kJ) were associated with lower \textit{ad-libitum} energy intake compared to CONT (3 199 kJ); while \textit{ad-libitum} energy intake for very HIIE was also lower compared to MICE (2974 kJ) and reduced free-living energy intake remained lower for up to 24 h after very HIIE. As such, these data suggest that HIIE induces longer lasting reductions in orexigenic signals and energy intake compared to MICE; therefore, higher exercise intensities may be more beneficial for appetite-related responses in overweight/obese populations.

There are several mechanisms which may contribute to the reduction in energy intake following HIE/HIIE. Given the orexigenic influence that acylated ghrelin exerts on energy intake and meal initiation, it is likely that exercise-induced reductions of this peptide partly influences the suppression of energy intake, as previously shown by Sim et al. (2014), Martins et al. (2015) and Holliday and Blannin (2017). The diversion of blood flow away from the gastrointestinal tract has been suggested to play a substantial role in the
suppression of acylated ghrelin during and following HIE (Broom et al., 2007; Clausen, 1977). Rowell (1974) and Clausen (1977) have previously indicated that during HIE, gastrointestinal blood flow may be reduced by ≤ 80 % and presented evidence that showed a reduction in splanchnic blood flow from resting levels of 1.6 L to 390 - 820 mL·min⁻¹ during moderate - intense upright exercise. Toshinai et al. (2007) corroborated these reports as they showed an inverse relationship between circulating ghrelin and exercise intensity. The authors further reported that changes in ghrelin were associated with changes in circulating epinephrine \( r = -0.53, p < 0.05 \) and norepinephrine \( r = -0.60, p < 0.001 \), suggesting that there is a sympathetic-mediated reduction in gastrointestinal blood flow which may directly decrease the delivery of ghrelin into circulation (King, Wasse, Stensel, & Nimmo, 2013; Toshinai et al., 2007).

Enhanced sensitivity to anorexigenic signals has also been suggested as a possible mechanism for reductions in energy intake following exercise (Borghouts & Keizer, 2000; Dyck, 2005). For instance, Mikines et al. (1988) showed that prolonged MICE (1 h cycling at 150 W) increased insulin action on glucose uptake for up to 48 h post-exercise. However, the importance of exercise intensity in relation to insulin sensitivity is somewhat equivocal (Braun, Zimmermann, & Kretchmer, 1995; Kang et al., 1996; Young, Enslin, & Kuca, 1989), with evidence suggesting that the total amount of work performed is more imperative (Borghouts & Keizer, 2000; Young et al., 1989). Young et al. (1989) compared insulin responses of seven trained men (VO₂max: 58 ± 3 mL·kg⁻¹·min⁻¹) and seven untrained men (VO₂max: 49 ± 2 mL·kg⁻¹·min⁻¹) during three separate trials, including i) CONT (40 h after the last training session), ii) LIE (14 h after 40 min at 40 % VO₂max) and iii) HIE (14 h after 40 min at 80 % VO₂max). Within-group responses for trained participants indicated that there were no significant differences between 3 h insulin responses between CONT [area under the curve (AUC): ≈ 3 400 μU·mL⁻¹·180min], LIE (AUC: ≈ 4 000 μU·mL⁻¹·180min) or HIE (AUC: ≈ 4 500 μU·mL⁻¹·180min) leading authors to suggest that repeated efforts of exercise are of more importance than any single bout of exercise at any intensity (Young et al., 1989). Also, leptin resistance has been shown to partially reverse with endurance training in rats placed on a high-fat diet (Steinberg et
al., 2004), suggesting that exercise of any intensity may also improve leptin sensitivity (Dyck, 2005). These mechanisms remain to be fully understood and conclusions should be made with caution given that some studies have presented findings which oppose the notion that HIE induces greater benefits for appetite regulation and energy intake compared to MICE (Howe et al., 2016; Martins et al., 2015).

Since 2014, two studies have shown beneficial appetite changes following exercise; however, they further suggest that there are no differences between HIIE and MICE-induced responses when energy expenditure is matched (Howe et al., 2016; Martins et al., 2015). Howe et al. (2016) conducted a study which recruited highly-trained endurance female athletes to complete two exercise trials, including MICE (60 % \( \text{VO}_{2\text{max}} \)) and HIE (85 % \( \text{VO}_{2\text{max}} \)) until 500 kcal of energy was expended. The authors reported that regardless of exercise intensity, acylated ghrelin was significantly lower \((p = 0.01)\), and PYY\(_{\text{total}}\) and GLP-1 were significantly higher \((p = 0.02 - 0.04)\) after exercise compared to BASE. Nevertheless, given that time (or lack thereof) may be a major exercise barrier for many individuals, the HIE protocol used by Howe et al. (2016) may be more enticing given that exercise duration was lower \((\approx 34 \text{ min})\) compared to MICE \((\approx 46 \text{ min})\). In addition, Martins et al. (2015) recruited 12 inactive, obese adults \((33 \pm 10 \text{ y}, \text{BMI}: 32 \pm 3 \text{ kg} \cdot \text{m}^2)\) to investigate the effects of multiple exercise intensities on appetite-related hormones, perceived appetite and energy intake. The trials included a i) CONT (resting in seated position), ii) MICE \((\approx 27 \text{ min}, 70 \% \text{HR}_{\text{max}}, 250 \text{ kcal})\) iii) HIIE \((\approx 18 \text{ min}, 85 - 90 \% \text{HR}_{\text{max}}, 8 \text{ s sprints: 12 s active recovery, 250 kcal})\), and iv) HIIE-0.5 \((\approx 9 \text{ min}, 85 - 90 \% \text{HR}_{\text{max}}, 8 \text{ s sprints: 12 s active recovery, 125 kcal})\) (Martins et al., 2015). Acylated ghrelin was significantly lower following MICE and HIIE compared to CONT \((p < 0.05)\); however, relative energy intake for the \textit{ad-libitum} lunch meal was lowest for MICE (-141 kcal) compared to HIIE (-87 kcal), HIIE-0.5 (-27 kcal) and CONT (+115 kcal) (Martins et al., 2015). The results presented by Martins et al. (2015) and Howe et al. (2016) suggest that HIIE protocols utilised may enhance or diminish appetite-related responses compared to MICE protocols due to several possibilities, such as the required energy expenditure reached to terminate exercise was too low (Broom et al., 2017) or that the duration of HIE
was too short to induce significant changes in appetite-related peptides in the respective participant groups (Holliday & Blannin, 2017).

Despite much of the current literature reporting favourable changes in appetite-related hormones and associated reductions in energy intake, perceived appetite may not entirely reflect these changes (Alkahtani, Byrne, Hills, & King, 2014; Broom et al., 2017; Sim et al., 2014; Thivel et al., 2012), or transient changes are reported post-exercise, regardless of intensity (Holliday & Blannin, 2017; Howe et al., 2016; Martins et al., 2015; Panissa et al., 2016). While disparities in HIIE and MICE protocols may partly explain these inconsistent findings, it is also conceivable that body composition, including higher fat mass and/or hedonic influence, such as mood states and habitual food choices, play a role in perceived appetite responses following acute exercise (Paspala et al., 2012). For example, circulating leptin is elevated in overweight/obese populations due to excessive fat mass; however, persistent overeating tends to remain (Benoit, Clegg, Seeley, & Woods, 2004), which may be difficult to alter with a single bout of exercise. The first of two potential mechanisms which have been proposed to explain this tendency is that despite elevated concentrations, circulating leptin is unable to penetrate the blood-brain barrier in adequate concentrations to activate anorexigenic neuroendocrine pathways (POMC, CART and α-MSH) and deactivate orexigenic neuroendocrine pathways (NPY and AgRP) (Paspala et al., 2012). The second mechanism, which has been postulated, is that some orexigenic signals (NPY and AgRP) in the hypothalamus become resistant to the actions of leptin (Hroussalas et al., 2008; Margetic, Gazzola, Pegg, & Hill, 2002; Paspala et al., 2012; Singh et al., 2009; Wilcox, 2005). The findings reported by Matos et al. (2017) and Martins et al. (2015) support the idea that there are other factors, apart from acute exercise per se, which influence perceived appetite. Ten overweight/obese men (27 ± 5 y, BMI: 28 ± 2 kg·m⁻²) reported an increase in perceived fullness following MICE (-19.5 mm, 20 min, ≈ 65 % of HRmax) and HIIE (-21.5 mm, 20 min, 10 × 60 s at ≈ 90 % HRmax), and a decrease in prospective food consumption after HIIE (+35.5 mm), while no significant difference was reported for perceived hunger (MICE: +1 mm, HIIE: +10.5
These results suggest that HIE may be required to alter perceived appetite variables to a greater extent within overweight/obese cohorts. Conversely, Martins et al. (2015) reported an increase in perceived hunger (≈ +1 cm) and a decrease in perceived fullness (≈ -1 cm), regardless of exercise intensity, indicating a potential negative perceptual response to exercise within an overweight/obese population. Whereas, Howe et al. (2016) reported a decrease in perceived hunger (≈ -10 - 30 mm) and desire to eat (≈ -15 - 20 mm) following both MICE (60 % \( \dot{V}O_{2\text{max}} \)) and HIE (85 % \( \dot{V}O_{2\text{max}} \)) within a group of highly-trained endurance women (\( n = 15, 31 \pm 7 \) y, 55 ± 4 mL·kg\(^{-1}\)·min\(^{-1}\)). These findings suggest that active populations may be more sensitive to exercise-induced changes in appetite-related hormones, compared to inactive counterparts (Howe et al., 2016). Since appetite-related responses appear to be different between active and inactive populations, it seems pertinent to investigate appropriate HIE/HIIE protocols for each respective group. Further, given that inactive populations are more likely to experience reduced hormone sensitivity and perceptual/behavioural impairments, such as overeating, due to insufficient sleep; it may be advantageous to explore i) the potential mitigating effects of exercise on appetite responses to sleep curtailment, and ii) the simultaneous appetite and sleep responses to differing exercise intensities.
Table 2.5 Previous research examining the effects of exercise intensity on appetite-related hormones, perceived appetite and energy intake.

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Exercise Intensity</th>
<th>Appetite Measures</th>
<th>Energy Intake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thivel et al. (2012)</td>
<td>n = 15 obese boys 14 y BMI 31 kg·m²</td>
<td>CONT (no exercise)</td>
<td>Hunger, NSD</td>
<td>24 h EI ↓ HIE</td>
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<tr>
<td></td>
<td></td>
<td>LIE (40 % VO₂max, 59 min)</td>
<td>Fullness, NSD</td>
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<tr>
<td></td>
<td></td>
<td>HIE (75 % VO₂max, 30 min)</td>
<td>Desire to eat, NSD</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>24 h CHO, 24 h PRO, 24 h FAT</td>
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<tr>
<td>Deighton et al. (2013)</td>
<td>n = 12 men 23 y BMI 24 kg·m²</td>
<td>CONT (no exercise)</td>
<td>Acylated ghrelin ↓ MICE, HIIE</td>
<td>El, NSD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MICE (65 % VO₂max, 60 min)</td>
<td>Hunger, ↑ HIIE</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>HIIE (6 × 30 s: 4 min, 30 min)</td>
<td>Fullness, ↑ MICE</td>
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<td>PFC, ↑ HIIE</td>
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<td></td>
<td>EI post-EX, ↓ Very HIIE</td>
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<td></td>
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<td></td>
<td>MICE &gt; HIIE-0.5</td>
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<tr>
<td>Alkahtani et al. (2014)</td>
<td>n = 12 inactive overweight/obese men 29 y BMI 29 kg·m²</td>
<td>MICE (5 min intervals at 20 % below and above maximal fat oxidation, 30 min)</td>
<td>Hunger, NSD</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>HIIE (15 s at 85 % VO₂peak: 15 s recovery, 18.5 min)</td>
<td>Fullness, NSD</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Desire to eat, NSD</td>
<td></td>
</tr>
<tr>
<td>Sim et al. (2014)</td>
<td>n = 17 overweight, inactive men 30 y BMI 28 kg·m²</td>
<td>CONT (supine rest, 30 min)</td>
<td>Acylated ghrelin ↓ Very HIIE</td>
<td>El post-EX ↓ Very HIIE, HIIE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MICE (60 % VO₂peak, 30 min)</td>
<td>Hunger, NSD</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>HIIE (60 s at 100 % VO₂peak: 240 s at 50 % VO₂peak, 30 min)</td>
<td>Fullness, NSD</td>
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<tr>
<td></td>
<td></td>
<td>Very HIIE (15 s at 170 % VO₂peak: 60 s at 32 % VO₂peak, 30 min)</td>
<td>Desire to eat, NSD</td>
<td></td>
</tr>
<tr>
<td>Martins et al. (2015)</td>
<td>n = 12 inactive overweight/obese adults (7 women)</td>
<td>CONT (no exercise)</td>
<td>Glucose ↑ Very HIIE</td>
<td>24 h EI ↓ All EX trials, MICE &gt; HIIE-0.5</td>
</tr>
<tr>
<td></td>
<td>33 y BMI 32 kg·m²</td>
<td>MICE (70 % HRmax, 250 kcal)</td>
<td>Acylated ghrelin ↑ MICE, HIIE</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>HIIE (85 - 90 % HRmax, 250 kcal)</td>
<td>Hunger, ↑ All trials</td>
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<tr>
<td></td>
<td></td>
<td>HIIE-0.5 (85 - 90 % HRmax, 125 kcal)</td>
<td>Fullness, ↓ All trials</td>
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<td></td>
<td></td>
<td></td>
<td>Desire to eat, ↓ All EX trials</td>
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<td></td>
<td>REI post-EX</td>
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<td></td>
<td></td>
<td></td>
<td>MICE &gt; HIIE-0.5</td>
<td></td>
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<tr>
<td>Study</td>
<td>Participants</td>
<td>Intervention</td>
<td>Acylation</td>
<td>Hunger</td>
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<td>------------------------------</td>
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<tr>
<td>Howe et al. (2016)</td>
<td>n = 15 highly-trained endurance women</td>
<td>MICE (60% VO_{2max}, 500 kcal) HIE (85% VO_{2max}, 500 kcal)</td>
<td>Acylated ghrelin PYY&lt;sub&gt;3-36&lt;/sub&gt;</td>
<td>Both trials</td>
</tr>
<tr>
<td>Panissa et al. (2016)</td>
<td>n = 11 physically active men (9 women)</td>
<td>CONT (no exercise) MICE (19 min, 60% MAP) HIE-15 (17 min, 100% MAP, 1 min passive recovery) HIE-all out (20 min, 60 × 8 s maximal effort: 12 s passive recovery)</td>
<td>Acylated ghrelin PYY&lt;sub&gt;3-36&lt;/sub&gt;</td>
<td>AUC HIE</td>
</tr>
<tr>
<td>Broom et al. (2017)</td>
<td>n = 9 healthy men</td>
<td>CONT (no exercise) MICE (52% VO_{peak}, 2510 kcal) HIE (75% VO_{2peak}, 2510 kcal)</td>
<td>Glucose</td>
<td>HIE</td>
</tr>
<tr>
<td>Holliday and Blannin (2017)</td>
<td>n = 12 endurance-trained men</td>
<td>CONT (no exercise) HIE-15 (15% VO_{2max}, 15 min) HIE-30 (15% VO_{2max}, 30 min) HIE-45 (15% VO_{2max}, 45 min)</td>
<td>Acylated ghrelin</td>
<td>HIE-45</td>
</tr>
<tr>
<td>Matos et al. (2017)</td>
<td>n = 10 overweight/obese men</td>
<td>MICE (65% HR_{max}, 20 min) HIE (90% HR_{max}; passive recovery, 20 min)</td>
<td>PYY</td>
<td></td>
</tr>
</tbody>
</table>

符号说明:
- ≈: 大约
- AUC: 区域下面积
- BMI: 体重指数
- CHO: 碳水化合物
- CON: 无运动
- EI: 能量摄入
- EX: 运动
- FAT: 脂肪
- HIE: 高强度间歇性训练
- HIEI: 高强度间歇性训练-间歇
- HR_{max}: 最大心率
- kJ: 千焦耳
- kcal: 千卡路里
- kg·m<sup>2</sup>: 千克每平方米
- MAP: 最大平均动脉压
- MICE: 中强度-持续性训练
- min: 分钟
- max: 最大
- %: 百分比
- ml·min<sup>-1</sup>: 每分钟毫升
- M: 千米
- m: 米
- PYY: 蛋白质
- PRO: 蛋白质
- PFC: 前瞻性食物摄入
- PRO: 蛋白质
- REI: 相对能量摄入
- s: 秒
- VO<sub>2peak</sub>: 峰值氧消耗
- VO_{2max}: 最大氧消耗
- PYY: 肽基酪氨酸
- ghrelin: 肥加林
- AUC: 面积
- HIIE: 高强度间歇性训练-间歇
- hunger: 饥饿
- NSD: 无显著差异
- P: 肉
- 103: 页

注意：具体数据需根据原始文献进行确认。
2.7.2 The effect of exercise time-of-day on appetite regulation and control

As outlined in Section 2.5.1, leptin and ghrelin have been shown to follow a circadian rhythm associated with the sleep-wake cycle (Arora, 2006; Copinschi et al., 2014; Espelund et al., 2005; Morselli et al., 2012); while PYY is primarily dependent on the timing of meals and number of calories ingested (Adrian et al., 1985). Given the natural circadian patterns and effects of timing of last meal on circulating hormones, it is highly probable that exercise-induced changes in concentrations would be different depending on the time of day exercise is performed. Nonetheless, the effects of exercise time-of-day on appetite-related hormones, and associated perceived appetite and energy intake have been largely unexplored (Table 2.6). Instead, much of the research (Section 2.7.1) has investigated appetite responses to exercise performed in the morning (Balaguera-Cortes et al., 2011; Broom et al., 2009; Panissa et al., 2016; Sim et al., 2014).

Of the studies which have explored exercise time-of-day effects on appetite, just one study has investigated leptin in conjunction to perceived appetite and energy intake (Bilski et al., 2016). This study recruited 24 moderately active men (27 ± 3 y, BMI: 23 kg·m⁻²) which were assigned into two groups, including i) an ad-libitum test meal group (n = 12, M) and ii) a no ad-libitum test meal group (n = 12, WM), to assess the effects of exercise on perceived appetite (Bilski et al., 2016). All participants completed four separate trials involving a morning (1100 h) and evening (2300 h) CONT (seated rest) trial, and a morning (1100 h) and evening (2300 h) HIIE (30 s Wingate anaerobic test) trial (Bilski et al., 2016). The authors reported that there were no between-trial differences for leptin; however, perceived hunger (M: -28 - 31 mm, WM: -21 -29 mm) and prospective food consumption (M: -25 - 28 mm, WM: -26 - 27 mm) were lower following HIIE compared to respective CONT, regardless of time-of-day (Bilski et al., 2016). Bilski et al. (2016) demonstrated that neither exercise nor meal-ingestion significantly changed leptin concentrations suggesting that the circadian pattern of this adipose-derived hormone may be sustained despite acute changes in physical activity, meal ingestion and sleep patterns. However, when insufficient sleep is experienced regularly, the diurnal rhythms of leptin have been shown to be disrupted, leading to reduced
satiety and increased risk of obesity (Maury, Hong, & Bass, 2014; Pietroiusti et al., 2010). As such, further research is required to investigate additional appetite-related hormones in response to differing exercise time-of-day to provide greater understanding of the influence of exercise on the circadian rhythms of these hormones.

Several other studies, while still limited, have investigated the effects of exercise time-of-day on perceived appetite and energy intake (Alizadeh et al., 2015; Maraki et al., 2005; O’Donoghue et al., 2010). Regarding perceived appetite, findings have been varied thus far as Alizadeh et al. (2015) reported no significant differences in perceived appetite or cravings for sweet and savoury foods following MORN (0800 - 1000 h), and AFT (1400 - 1600 h) exercise (30 min running at VT); whereas Maraki et al. (2005) observed that MORN and EVEN both altered perceived appetite variables. To expand, 12 women (28 ± 6 y, BMI: 21 ± 2 kg·m²) completed four separate trials, similar to Bilski et al. (2016), which included a morning (0815 h) and evening (1915 h) CONT (1 h, seated rest), and a morning (0815 h) and evening (1915 h) exercise trial (1 h, aerobic and muscle conditioning class) (Maraki et al., 2005). The perceived appetite responses indicated, that after morning and evening exercise, hunger (+ 34 - 42 mm) and prospective food consumption (+ 20 - 31 mm) increased, while fullness (- 29 - 45 mm) decreased compared to CONT (Maraki et al., 2005), suggesting the potential for increased energy intake post-exercise. Instead, authors observed a reduction in relative energy intake for the whole day following morning exercise (- 1 028 kJ) and a decrease in relative energy intake for the dinner meal following evening exercise (- 1 559 kJ) compared to CONT (Maraki et al., 2005). As such, despite negative changes in perceived appetite, exercise (regardless of time-of-day) may still decrease energy intake. These results have not been corroborated by similar studies, including O’Donoghue et al. (2010) and Alizadeh et al. (2015), who reported no significant difference in energy intake for up to 24 - 26 h following MORN (0700 - 1000 h), AFT (1400 - 1600 h) or EVEN (1700 h).
Given the limited data, mechanisms for appetite responses to exercise time-of-day have not yet been explored. However, previous findings have shown that due to hormonal and hedonic factors, overweight/obese persons may be more susceptible to overeating during the afternoon and evening given reports of increased perceived hunger and decreased perceived fullness at these times (Carnell et al., 2017). As such, irrespective of the misaligned findings of current literature, the mere participation in exercise at these times may reduce the number of calories that would otherwise be consumed during sedentary activities. As such, further exploration is warranted given the association between low physical activity, eating behaviours and prevalence of sleep problems among middle-aged adults, which have yet to be recruited for studies investigating exercise time-of-day on appetite-related responses.
Table 2.6 Previous studies that have investigated the exercise time-of-day effect on appetite regulation and control.

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Exercise Time-of-Day</th>
<th>Appetite Measures</th>
<th>Energy Intake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hormones</td>
<td>Perceived Appetite</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Hunger</td>
<td>Fullness</td>
</tr>
<tr>
<td>Maraki et al. (2005)</td>
<td>n = 12 healthy women</td>
<td>MORN-CONT (0815 h)</td>
<td>↑ MORN-EX, EVEN-EX</td>
<td>↓ MORN-EX, EVEN-EX</td>
</tr>
<tr>
<td></td>
<td>28 y</td>
<td>MORN-EX (0815 h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI 21 kg·m²</td>
<td>EVEN-CONT (1915 h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>EVEN-EX (1915 h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O'Donoghue et al. (2010)</td>
<td>n = 9 active men</td>
<td>CONT</td>
<td></td>
<td>PFC</td>
</tr>
<tr>
<td></td>
<td>20 y</td>
<td>MORN (0700 h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMI 22 kg·m²</td>
<td>EVEN (1700 h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alizadeh et al. (2015)</td>
<td>n = 50 overweight women</td>
<td>MORN (0800 - 1000 h)</td>
<td>Hunger</td>
<td>Fullness</td>
</tr>
<tr>
<td></td>
<td>33 y</td>
<td>AFT (1400 - 1600 h)</td>
<td>NSD</td>
<td>NSD</td>
</tr>
<tr>
<td></td>
<td>BMI 27 kg·m²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilski et al. (2016)</td>
<td>n = 24 moderately-active men</td>
<td>MORN-CONT (1100 h)</td>
<td>Leptin</td>
<td>Hunger</td>
</tr>
<tr>
<td></td>
<td>27 y</td>
<td>MORN-EX (1100 h)</td>
<td>NSD</td>
<td>↓ MORN-EX</td>
</tr>
<tr>
<td></td>
<td>BMI 23 kg·m²</td>
<td>EVEN-CONT (2300 h)</td>
<td></td>
<td>EVEN-EX</td>
</tr>
<tr>
<td></td>
<td>Ad-libitum meal group (n = 12)</td>
<td></td>
<td></td>
<td>PFC</td>
</tr>
<tr>
<td></td>
<td>No meal group (n = 12)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

_AFT_: afternoon exercise; _BF_: breakfast; _BMI_: body mass index; _CHO_: carbohydrates; _CONT_: no exercise trial; _↓_: decrease; _D_: dinner; _EI_: energy intake; _EVEN_: evening exercise; _EX_: exercise; _FAT_: fats; _kg·m²_: h: hours; _↑_: increase; _kgs per metre squared; _L_: lunch; _MORN_: morning exercise; _n_: number of participants; _NSD_: no significant difference; _PFC_: prospective food consumption; _PRO_: proteins; _PYY_: peptide tyrosine tyrosine; _REI_: relative energy intake; _WD_: whole day; _y_: years.
2.8 Therapeutic effects of exercise on mood and wellness

The therapeutic effects of exercise on mood and wellness have been shown to be beneficial for reducing feelings of fatigue, depression and stress, while simultaneously improving feelings of vigour and self-esteem within many non-clinical and clinical populations (Basso & Suzuki, 2017; Donnelly et al., 2009; Fogelholm, 2010; Giacobbi et al., 2005). For instance, Hansen et al. (2001), who recruited 21 college students, revealed that peak improvements of vigour (+ 1.9) and concurrent reductions in fatigue (- 3.8), confusion (- 2.9) and TMD (- 15.8) were reached within 20 min of MICE (60 % VO₂max) compared to 10 min (+ 1.2, - 3.9, - 1.1, - 12.0) and 30 min (+ 0.6, - 2.8, - 2.1, - 11.5) at the same intensity. There are several contributing factors to exercise-induced mood improvements, which include the increase of neurochemicals such as lactate and cortisol, neurotrophins including brain derived neurotrophic factor and insulin-like growth factor 1, neurotransmitters such as dopamine and norepinephrine, and neuromodulators such as endogenous opioids and endocannabinoids (Basso & Suzuki, 2017). Given these effects, exercise has been explored as a possible mitigator of detrimental mood states induced by TSD; however, current literature suggests that exercise only acts as an additional stressor and induces further decreases in alertness and increases fatigue (LeDuc, Caldwell, & Ruyak, 2000; Scott et al., 2006). As previously expressed, TSD studies represents the extremes of sleep loss and may not reflect sleep patterns of the general population at large. Instead, future research would benefit from investigating the effects of exercise on mood states following RES and FRAG protocols that mimic reported sleep patterns of many adults (Adams et al., 2017).
2.9 Conclusion

In conclusion, sleep, appetite and exercise do appear to closely intertwine in a synergistic manner (Keating et al., 2017; Kredlow et al., 2015). It is apparent that insufficient sleep, which is common among middle-aged adults, has detrimental effects on mood and appetite whereby increased fatigue and stress lead to a greater propensity to consume calorie-dense foods (Adams et al., 2017; Moubarac et al., 2013; Nedeltcheva et al., 2009). Conversely, while it is suggested that acute exercise, regardless of intensity or time-of-day, induces varied improvements in sleep, including TST and duration of stage N3 sleep, much of the current literature has only explored good sleepers unlikely to experience large changes due to potential ceiling effects (Youngstedt, 2005). Conversely, growing evidence suggests that HIE likely induce long-lasting reductions in orexigenic signals which lead to suppression of perceived hunger and energy intake compared to MICE (Sim et al., 2014; Thivel et al., 2012). However, the evidence for the effects of exercise time-of-day on appetite-related hormones, perceived appetite and energy intake have been largely unexplored.

Further insight is required to determine the simultaneous interactions of sleep, appetite and exercise, while considering other influencing factors, including physiological, perceptual and behavioural responses following sleep manipulation and exercise interventions (i.e. differing intensities and time-of-day). Moreover, given the current lack of research recruiting middle-aged adults, this population require age-appropriate evidence for changes in sleep characteristics, and appetite-related hormones, perceived appetite and energy intake following exercise interventions as responses may be different to their younger counterparts (Alves et al., 2011; Copinschi et al., 2014).
Chapter Three: The effects of sleep restriction, fragmentation and extension on appetite and mood states before and after short-duration, vigorous exercise in inactive, middle-aged men

In preparation for submission to Applied Physiology, Nutrition and Metabolism
Title: The effects of sleep restriction, fragmentation and extension on appetite and mood states before and after short-duration, vigorous exercise in inactive, middle-aged men

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Conflicts of Interest:

There are no conflicts of interest.
Abstract
This study aimed to compare the effects of normal sleep (CONT), sleep restriction (RES), sleep fragmentation (FRAG) and sleep extension (EXT) on perceived appetite, appetite-related hormones and mood states. Nine inactive men (44 ± 8 y) completed four separate, randomised trials which involved three consecutive nights of CONT (6 - 8.5 h), RES (4 h), FRAG (6 - 8.5 h, interrupted at 2 h intervals) or EXT (10 h). Following the third sleep night, appetite-related hormones (ghrelin, leptin, peptide tyrosine tyrosine: PYY\text{total}), glucose, perceived appetite and mood states were assessed prior to (post-sleep manipulation: SM) and after (post-exercise: EX) a 20 min self-paced cycling effort at a rating of perceived exertion (RPE) of 15. For RES, PYY\text{total} was lower compared to EXT and FRAG at both timepoints (p ≤ 0.03). However, while there were no between-trial differences for ghrelin post-SM, levels were higher post-EX for RES and EXT compared to CONT and FRAG (p ≤ 0.03). There were no between-trial differences for leptin (p > 0.05). Desire to eat and prospective food consumption were higher for RES compared to FRAG at post-SM and post-EX (p = 0.05); while the desire for sweet foods was higher for RES compared to CONT at post-SM (p = 0.04). Post-SM fatigue was higher for RES compared to all other trials (p ≤ 0.02) and remained high at post-EX (p ≤ 0.05). Interestingly, perceived sleep quality was higher at post-SM for CONT and RES (p = 0.01 - 0.05); whereas, stress was higher for EXT compared RES and CONT (p ≤ 0.02). Nevertheless, post-SM total mood disturbance was higher for RES and FRAG compared to CONT and EXT (p ≤ 0.05); however, there were no further between-trial differences for mood states post-EX (p > 0.05). While sleep curtailment was detrimental to appetite and mood variables, results suggest that RES had a greater negative effect on appetite-related hormones, perceived appetite and cravings indicative of increased energy intake. Conversely, FRAG appeared to induce greater detriments to mood state. Still, vigorous exercise may mitigate appetite and mood responses to sleep curtailment; while, the combination of EXT and vigorous exercise is unlikely to induce additional improvements in appetite and mood within inactive, middle-aged men.

Keywords: sleep deprivation, actigraphy, cycling, appetite regulation
Introduction

Sleep is essential for physiological and cognitive restoration, repair and memory consolidation (Chaput, Després, Bouchard, & Tremblay, 2008; Eidelman, 2002; Wong et al., 2013); yet, approximately 30% of adults are achieving \( \leq 6 \) h of sleep per night, which is well below recommendations (Adams et al., 2017; Chaput et al., 2009; Choi et al., 2008; Spiegel et al., 2009). Consequently, inadequate sleep has been linked with behavioural, psychological and physiological changes, including increased energy intake (changes in diurnal patterns of appetite-related hormones) (Brondel et al., 2010; Spiegel et al., 2004b) and reduced psychological wellness (increased depression, anxiety, fatigue and stress) (Ablin et al., 2013; Kahn et al., 2014; Scott et al., 2006). These appetite and mood changes in response to chronic sleep curtailment have been shown to increase the prevalence of many lifestyle diseases, including cardiovascular disease and T1DM (Buxton & Marcelli, 2010; Knutson & Van Cauter, 2008), which have associated health, social and economic implications (Sharma & Kavuru, 2010).

On closer examination of the effects of sleep on appetite, sleep loss has been shown to induce elevated acylated ghrelin levels and decrease circulating levels of leptin (Spiegel et al., 2004b; Taheri et al., 2004), due to neuroendocrine pathways associated with circadian disruption (Mullington et al., 2003; Rayner & Trayhurn, 2001). These changes in appetite hormone profiles increase feelings of hunger and cravings for calorie-dense foods (Spiegel et al., 2004b) and excess energy intake (Brondel et al., 2010; Nedeltcheva et al., 2009) when sleep deprived. This appetite-stimulating response in a sleep deprived state is believed to facilitate alertness and reduce feelings of fatigue (Chaput, 2014; Persson & Mårtensson, 2006). However, some studies have not observed these appetite changes following sleep loss (Markwald et al., 2013; St-Onge et al., 2012b) and the potential age-related responses have not been explored extensively, as much of the appetite and sleep literature has focussed on young adults (Gonnissen et al., 2013; Magee et al., 2009; Spiegel et al., 2004b).
In addition to hormone changes, both short sleep (i.e. RES) and disrupted sleep (i.e. FRAG) have a negative effect on mood states and psychological wellbeing; and further evidence suggests that FRAG leads to greater negative mood changes compared to RES (Finan et al., 2015). Conversely, enforced EXT in athletes has been shown to improve overall mood states, including reduced fatigue and increased vigour (Kamdar et al., 2004; Mah et al., 2011). Nonetheless, the participants recruited by these studies were young adults (Finan et al., 2015; Kamdar et al., 2004; Mah et al., 2011); as such, due to differences in sleep needs and the age-related sleep changes that tend to occur from approximately 35 y of age, results may not be applicable to middle-aged adults (Copinschi et al., 2014). Given that a large proportion of middle-aged adults experience persistent sleep problems, it may be beneficial to compare the effects of enforced RES, FRAG and EXT on mood states to assess if changes in sleep duration effect mood states.

While inadequate sleep may contribute to the above-mentioned outcomes for appetite regulation and psychological wellbeing, vigorous exercise appears to have a beneficial effect on these outcomes, independent of sleep, as indicated by findings from Chapter Three. More specifically, exercise has been shown to reduce acylated ghrelin, increase anorexigenic hormones, such as \( \text{PYY}_{\text{total}} \) (Sim et al., 2014), and reduce energy intake for up to 24 h after exercise (Sim et al., 2014; Thivel et al., 2012). Given these effects, it is possible that vigorous exercise may mitigate the upregulation of appetite that occurs when sleep deprived; therefore, reducing the risk of the overconsumption of food. Meanwhile, vigorous exercise has a well-established analgesic effect on negative mood states such as fatigue, depression and anxiety (Hoffman & Hoffman, 2008; Puetz, O’Connor, & Dishman, 2006). Accordingly, researchers have incorporated vigorous exercise during TSD studies to investigate its role as a potential mediator for negative mood states (Scott et al., 2006). However, results thus far suggest that exercise may exacerbate negative mood outcomes that are induced by sleep deprivation, such as decreased alertness and increased fatigue (Scott et al., 2006). Due to the extreme nature of TSD and
Chapter 3: Study 1

The unlikeliness of this being common practice, it would be advantageous to assess the use of vigorous exercise after prolonged RES, FRAG and EXT to determine if exercise mediates negative appetite and mood states induced by sleep loss, and if positive moods are enhanced due to the combination of extended sleep and exercise.

As the responses and interactions of appetite and mood states following sleep manipulation have not yet been investigated in an inactive, middle-aged population group, this study aimed to examine the effect of RES, FRAG and EXT, compared to normal sleep on perceived appetite, appetite-related hormones and mood states. A further aim was to investigate the effect of vigorous exercise on perceived appetite and appetite-related hormones, and mood states following normal sleep (CONT), RES, FRAG and EXT. It was hypothesised that: (1) there would be a reduction in anorexigenic hormone concentrations, and positive mood states (vigour); while acylated ghrelin, perceived hunger, food cravings and fatigue would increase following RES and FRAG compared to CONT and EXT. Also, it was hypothesised that vigorous exercise would reduce orexigenic signals and perceived hunger, and improve mood states. However, responses would be blunted following RES and FRAG compared to CONT, while EXT would provide additional benefits to appetite and mood variables induced by vigorous exercise.

Methods

Participants

Nine inactive, overweight men [44 ± 8 y; blood pressure (BP): 126 ± 7/83 ± 7 mmHg; BMI: 28 ± 4 kg·m⁻²; WHR: 0.96 ± 0.04] volunteered to participate in the study. Inclusion criteria stipulated that participants had no previous or current diagnosed sleep disorders and regularly achieved 6.5 - 8.5 h sleep per night, not on medication that may affect sleep, not engaging in ≥ 150 min of moderate-intensity exercise per week, and free from any conditions which may be exacerbated by accumulated
sleep curtailment or vigorous exercise. Sleep was assessed by the STOP-BANG questionnaire (Chung et al., 2008), the ESS (Johns, 1991), and the PSQI (Buysse et al., 1989). If participants’ scores indicated high risk of OSA (5 - 8 in the STOP-BANG questionnaire) or excessive sleepiness (16 - 24 in the ESS), they were excluded from the study. A pre-exercise medical health questionnaire (Appendix B) was also completed by each participant prior to engaging in the study to assess risk of adverse responses to strenuous activity. The study was approved by the Institution’s Human Ethics Committee and written informed consent was attained from all participants prior to data collection.

**Familiarisation**

Familiarisation was completed prior to the experimental trials and included the assessment of blood pressure; height and body mass to calculate BMI; and waist and hip girths to calculate WHR. Participants were accustomed to all testing equipment and a 20 min self-paced cycling bout performed on a stationary cycle ergometer pre-set at a fan resistance of 4 and no magnetic resistance (Wattbike Trainer, Wattbike Ltd, Nottingham, UK). Participants were required to pedal at a self-selected cadence which equated to 15 (hard) on the 6 - 20 RPE scale (Borg, 1982). During this session, participants were aware of their heart rate, power output and the exercise duration at all times.
Figure 3.1 Schematic overview of the study design including three days of either normal sleep (CONT), sleep restriction (RES), sleep extension (EXT) or sleep fragmentation (FRAG) following by laboratory testing ($n = 9$).
Experimental Trials

On four separate occasions, participants were randomly assigned an experimental trial, each separated by a minimum of seven days. Experimental trials consisted of three consecutive nights of either CONT (6.5 - 8.5 h) in which participants maintained regular bed and wake times; RES (4 h) in which participants were required to adhere to a 0200 h bedtime and wake at 0600 h; EXT (10 h) in which participants were required to adhere to a 2100 h bedtime and wake at 0700 h; and FRAG in which bed and wake times were consistent with normal sleep patterns (determined by responses to question 1 and 3 in the PSQI), but sleep was interrupted by intermittent alarms at 2300 h, 0100 h, 0300 h and 0500 h (See Figure 3.2). Participants were instructed to turn off their alarm, and walk to the door and back before returning to sleep. During this time participants were required to refrain from daytime naps and vigorous physical activity, wear a wrist actigraph (Actiware 2, Philips Respironics, Andover, MA), and document bedtime, wake time, and all food and drink intake in a diary. Participants were also required to abstain from alcohol and caffeine 10 h prior to each laboratory visit which commenced at 0800 - 0900 h the morning following the third night of sleep manipulation.

The morning of laboratory testing, participants consumed a standardised breakfast (75 % carbohydrate; 15 % fat; 10 % protein; 2335 kJ) within 30 min of waking. Upon arrival to the laboratory, participants completed a wellness questionnaire (McLean et al., 2010), POMS (Grove & Prapavessis, 1992), FCQ-State (Cepeda-Benito et al., 2000), indicated perceived appetite on validated VAS (Flint et al., 2000), and a capillary blood sample was obtained from the fingertip for subsequent analysis (detailed later). Participants then completed a 20 min self-paced cycling bout on a stationary cycle ergometer (Wattbike Trainer, Wattbike Ltd, Nottingham, UK) and were required to cycle at an intensity which was perceived as hard (15) on the 6 - 20 RPE scale (Borg, 1982). Immediately after exercise, a second capillary blood sample was collected from the fingertip for later analysis. Lastly,
participants reported perceived appetite, and completed the wellness questionnaire, POMS and FCQ-State.

**Actigraphy**

Actigraphy data were obtained from participants for the duration of each experimental trial. The data were downloaded and assessed to ensure participants complied with the sleep requirements (previously outlined) for the respective trials. Data were then averaged across the three nights to indicate mean sleep quantity for each trial. Actigraph measurements were recorded in 1 min epochs (Esliger & Tremblay, 2006) and analysed using Actiware v5.70 software (Philips Respironics, Pittsburgh, USA). All non-wearing times were excluded from the analysis and bed and wake times were manually entered from data provided in the sleep record. All remaining epochs were assessed to determine TIB (period between bedtime and wake time), TST (time asleep during time in bed), SOL (period between bedtime and sleep onset), SE (percent of time in bed spent sleeping), WASO (total time awake after sleep onset) and awakenings (number of awakenings during sleep period) (Knutson et al., 2007a).

**Perceived Appetite, Food Cravings and Appetite-Related Hormones**

Perceived hunger, fullness, desire to eat and prospective food consumption were assessed using a VAS comprised of straight lines (100 mm) accompanied by a question with words anchored at opposing ends, representing extreme states of each variable (Appendix B) (Flint et al., 2000). The FCQ-State consisted of 23 questions adapted to relate to cravings for savoury and sweet foods, and general food cravings (Cepeda-Benito et al., 2000). Each question was scored on a Likert scale from 1 (strongly disagree) to 5 (strongly agree) indicating cravings felt at the time of completing the questionnaire. A 600 μl capillary blood sample was collected from a fingertip post-sleep manipulation (post-SM) and
post-exercise (post-EX). To assist vasodilation, the hand was submerged in a bowl of warm water for 5 min prior to blood draw. Blood glucose concentration was measured directly from the fingertip using an Accu-Chek Performa (Roche, Manheim, Germany). The remaining blood was immediately aliquoted into pre-chilled EDTA tubes (Becton Dickinson, Sydney, Australia) treated with serine protease inhibitor (25 μl per 600 μl of blood; Pefabloc® SC, Sigma-Aldrich, St. Louis, USA) and then immediately centrifuged at 3000 rpm for 10 min. Plasma obtained was stored at -80 °C and later analysed according to manufacturer’s instructions for acylated ghrelin, leptin and PYY<sub>total</sub> using a commercially available assay kit (Milliplex, Millipore Corporation, MA, USA). The intra- and inter-assay coefficient of variation for acylated ghrelin, leptin and PYY<sub>total</sub> concentration were < 10 % and < 15 %.

**Wellness and Mood States**

The wellness questionnaire included five items, two of which related to physical wellbeing (fatigue and general muscle soreness) and three related to psychological wellbeing (sleep quality, stress, mood). Participants subjectively rated each item post-sleep manipulation and post-exercise on a Likert scale from 1 (feeling as bad as possible) to 5 (feeling as good as possible) (McLean et al., 2010). TMD was calculated using the sum of all five items. The POMS short-version consisted of 40 items to assess six mood variables, including tension, anger, fatigue, depression, esteem-affect, vigour and confusion. A TMD score was calculated using the following equation: TMD = [(tension + anger + fatigue + depression + confusion) - (esteem-affect + vigour)] (Grove & Prapavessis, 1992).

**Statistical Analysis**

A priori sample size calculations for a repeated-measures ANOVA was performed using G*Power (version 3.1.9.2) which confirmed that a sample size of nine would provide a power of 83 % which was adequate for the input parameters (appetite-related hormones) (Balaguera-Cortes et al., 2011; Sim et
Data are reported as mean ± SD and statistical significance was accepted at p ≤ 0.05. A repeated-measures (trial × time) ANOVA with Tukey’s post hoc were used to determine significant differences for actigraphy variables, perceived appetite, appetite-related hormones and glucose, and mood and wellness variables.

Results

Sleep Questionnaires and Actigraphy

The results for the pre-screening questionnaires showed that 11% of participants had high risk of OSA (mean STOP-BANG score: 1.9 ± 0.9) and excessive sleepiness (mean ESS score: 5.2 ± 2.9), and 33% reported poor sleep quality (mean PSQI score: 4.1 ± 2.0). As outlined in Table 3.1, bedtime for RES was significantly later compared to all other trials (p = 0.001); while, bedtime for CONT was later compared to EXT and FRAG (p = 0.001). During RES, TIB, TST and WASO were shorter (p ≤ 0.01); and number of awakenings were lower (p ≤ 0.002) compared to all other trials. In addition, SOL was significantly shorter for RES compared to CONT and FRAG (p ≤ 0.03). During EXT, TIB and TST were significantly longer compared to all other trials (p ≤ 0.02), and WASO was longer and number of awakenings were higher for EXT compared to CONT (p ≤ 0.007). During FRAG, TIB, TST and WASO were longer, and number of awakenings higher compared to CONT (p ≤ 0.03). There were no between-trial differences for wake time or SE (p > 0.05).
Table 3.1 Actigraphy data during the three consecutive nights of normal sleep (CONT), sleep restriction (RES), sleep extension (EXT) and sleep fragmentation (FRAG) (Mean ± SD; n = 9).

<table>
<thead>
<tr>
<th></th>
<th>CONT</th>
<th>RES</th>
<th>EXT</th>
<th>FRAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of nights participants met study requirements (%)</td>
<td>94 ± 17</td>
<td>96 ± 11</td>
<td>96 ± 11</td>
<td>93 ± 22</td>
</tr>
<tr>
<td>Bedtime (hh:mm)</td>
<td>22:36 ± 0:41</td>
<td>1:53 ± 0:41&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21:13 ± 0:29&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>21:39 ± 0:45&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Wake time (hh:mm)</td>
<td>7:01 ± 0:25</td>
<td>6:35 ± 0:51</td>
<td>7:21 ± 0:22</td>
<td>7:01 ± 0:44</td>
</tr>
<tr>
<td>Time in bed (hh:mm)</td>
<td>8:22 ± 0:21</td>
<td>4:42 ± 0:28&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10:05 ± 0:25&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>9:17 ± 0:44&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total sleep time (hh:mm)</td>
<td>6:36 ± 0:32</td>
<td>3:43 ± 0:27&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8:05 ± 0:47&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>7:16 ± 0:30&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sleep onset latency (min)</td>
<td>30.9 ± 16.5</td>
<td>9.2 ± 6.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>26.6 ± 24.2</td>
<td>20.9 ± 14.7&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sleep efficiency (%)</td>
<td>78.9 ± 4.9</td>
<td>79.1 ± 5.6</td>
<td>80.4 ± 6.3</td>
<td>77.8 ± 2.8</td>
</tr>
<tr>
<td>Wake after sleep onset (min)</td>
<td>57.2 ± 15.6</td>
<td>27.8 ± 8.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>74.8 ± 16.1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>82.7 ± 20.9&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Awakenings (#)</td>
<td>29.0 ± 7.1</td>
<td>15.6 ± 4.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>38.7 ± 7.5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>35.3 ± 8.9&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Indicates significant difference compared to CONT (p ≤ 0.03).
<sup>b</sup> Indicates significant difference compared to RES (p ≤ 0.001).
<sup>c</sup> Indicates significant difference compared to EXT (p ≤ 0.001).

* h: hours; min: minutes; n: number of participants; %: percent; ±: plus-minus sign; #: total number.
Appetite-Related Hormones

There were no between-trial differences for acylated ghrelin post-SM; however, post-EX acylated ghrelin was higher for RES and EXT compared to CONT (p ≤ 0.03) and FRAG (p ≤ 0.001; Figure 3.2A). Post-SM and post-EX PYY\textsubscript{total} were lower for RES compared to EXT and FRAG (p ≤ 0.03; Figure 3.2C). Also, post-SM glucose was higher for CONT compared to EXT (p = 0.01); whereas, post-EX glucose for RES was higher compared to CONT and EXT (p ≤ 0.03; Figure 3.2D). There were no between-trial differences for post-SM or post-EX leptin (p > 0.05; Figure 3.2B).

Perceived Appetite and Food Cravings Questionnaire - State

Post-SM and post-EX desire to eat and prospective food consumption were higher for RES compared to FRAG (p ≤ 0.05), while there were no other differences between all other trials (p > 0.05; Figure 3.3). There was no trial \times time interaction for perceived hunger (p = 0.37) or perceived fullness (p = 0.62; Figure 3.3). However, there was a main effect of time for fullness which decreased from post-SM to post-EX for all trials (p = 0.004; Figure 3.3B).

With respect to cravings (Table 3.2), higher post-SM desire for sweet foods were reported for RES compared to CONT (p = 0.04). At post-SM, anticipation of positive reinforcement from eating savoury and sweet foods were greater for EXT compared to FRAG (p ≤ 0.05), while anticipation of relief from negative states and feelings as a result of eating scores were higher for RES compared to CONT and FRAG (p ≤ 0.03). Post-EX EXT scores for positive reinforcement from eating savoury remained higher compared to FRAG (p = 0.05); while, positive reinforcement from eating sweet scores for EXT were higher compared to CONT (p = 0.01). Post-EX anticipation of relief from negative states and feelings as a result of eating scores remained higher for RES compared to CONT and FRAG (p ≤ 0.03). There were no between-trial differences for desire for savoury foods, lack of control over eating, and thoughts or preoccupation with savoury or sweet foods, or craving as a physiological state (p ≥ 0.31).
Figure 3.2 A. acylated ghrelin; B. leptin; C. peptide tyrosine tyrosine (PYYtotal); and D. glucose for post-sleep manipulation (post-SM) and post-exercise (post-EX) for normal sleep (CONT), sleep restriction (RES), sleep extension (EXT), and sleep fragmentation (FRAG) (Mean ± SD; n = 9). mmol·l⁻¹: millimoles per litre; pg·ml⁻¹: picograms per millilitre.

- d Indicates significant difference between CONT and RES (p ≤ 0.03).
- e Indicates significant difference between CONT and EXT (p ≤ 0.03).
- f Indicates significant difference between RES and EXT (p ≤ 0.03).
- g Indicates significant difference between RES and FRAG (p ≤ 0.02).
- h Indicates significant difference between EXT and FRAG (p ≤ 0.001).
Figure 3.3 A. perceived hunger; B. perceived fullness; C. desire to eat; and D. prospective food consumption (PFC) for post-sleep manipulation (post-SM) and post-exercise (post-EX) for unaltered sleep (CONT), sleep restriction (RES), sleep extension (EXT), and sleep fragmentation (FRAG) (Mean ± SD; n = 9). mm: millimetres.

* Indicates significant difference between RES and FRAG (p ≤ 0.05).

* Indicates main effect of time for all trials (p ≤ 0.004).
### Table 3.2 Food Cravings post-sleep manipulation (post-SM) and post-exercise (post-EX) following three nights of normal sleep (CONT), sleep restriction (RES), sleep extension (EXT) and sleep fragmentation (FRAG) (Mean ± SD; n = 9).

<table>
<thead>
<tr>
<th></th>
<th>CONT Post-SM</th>
<th>CONT Post-EX</th>
<th>RES Post-SM</th>
<th>RES Post-EX</th>
<th>EXT Post-SM</th>
<th>EXT Post-EX</th>
<th>FRAG Post-SM</th>
<th>FRAG Post-EX</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intense desire for:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Savoury</td>
<td>7.1 ± 3.1</td>
<td>7.1 ± 3.4</td>
<td>11.8 ± 10.0</td>
<td>12.1 ± 10.1</td>
<td>8.4 ± 5.6</td>
<td>9.3 ± 8.0</td>
<td>8.0 ± 5.3</td>
<td>9.6 ± 7.6</td>
</tr>
<tr>
<td>Sweet</td>
<td>4.9 ± 2.0</td>
<td>5.0 ± 1.9</td>
<td>6.9 ± 4.3</td>
<td>6.0 ± 1.7</td>
<td>6.7 ± 3.1</td>
<td>5.3 ± 2.1</td>
<td>5.7 ± 2.9</td>
<td></td>
</tr>
<tr>
<td><strong>Positive Reinforcement:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Savoury</td>
<td>5.9 ± 1.5</td>
<td>6.9 ± 3.4</td>
<td>6.1 ± 3.2</td>
<td>8.0 ± 3.5</td>
<td>6.8 ± 2.2</td>
<td>8.2 ± 2.8</td>
<td>5.8 ± 2.0</td>
<td>6.7 ± 3.3</td>
</tr>
<tr>
<td>Sweet</td>
<td>6.4 ± 3.2</td>
<td>6.0 ± 2.9</td>
<td>6.5 ± 3.3</td>
<td>7.4 ± 3.1</td>
<td>6.4 ± 1.8</td>
<td>7.6 ± 2.7</td>
<td>5.8 ± 2.0</td>
<td>6.8 ± 3.5</td>
</tr>
<tr>
<td><strong>Relief from Negative States:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Savoury</td>
<td>6.4 ± 3.2</td>
<td>7.3 ± 3.0</td>
<td>8.9 ± 3.6</td>
<td>8.4 ± 3.5</td>
<td>8.0 ± 1.9</td>
<td>8.1 ± 2.8</td>
<td>7.3 ± 2.4</td>
<td>7.3 ± 2.6</td>
</tr>
<tr>
<td>Sweet</td>
<td>4.6 ± 1.8</td>
<td>4.6 ± 2.4</td>
<td>6.3 ± 3.3</td>
<td>5.8 ± 3.1</td>
<td>5.2 ± 1.6</td>
<td>5.7 ± 2.0</td>
<td>4.7 ± 1.9</td>
<td>5.4 ± 2.8</td>
</tr>
<tr>
<td><strong>Lack of Control</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Savoury</td>
<td>5.4 ± 2.1</td>
<td>5.4 ± 2.6</td>
<td>6.5 ± 3.2</td>
<td>6.6 ± 3.1</td>
<td>5.8 ± 1.7</td>
<td>6.7 ± 2.3</td>
<td>5.2 ± 2.2</td>
<td>6.0 ± 2.1</td>
</tr>
<tr>
<td>Sweet</td>
<td>4.6 ± 1.8</td>
<td>4.6 ± 2.4</td>
<td>6.3 ± 3.3</td>
<td>5.8 ± 3.1</td>
<td>5.2 ± 1.6</td>
<td>5.7 ± 2.0</td>
<td>4.7 ± 1.9</td>
<td>5.4 ± 2.8</td>
</tr>
<tr>
<td>Hunger</td>
<td>6.6 ± 2.9</td>
<td>6.9 ± 3.2</td>
<td>7.3 ± 3.7</td>
<td>7.0 ± 4.1</td>
<td>6.0 ± 2.2</td>
<td>7.7 ± 2.6</td>
<td>5.8 ± 2.4</td>
<td>7.6 ± 2.9</td>
</tr>
</tbody>
</table>

*Intense desire for:* an intense desire to eat; *positive reinforcement:* anticipation of positive reinforcement that may result from eating; *relief from negative states:* anticipation of relief from negative states and feelings as a result of eating; *lack of control:* lack of control over eating and thoughts or preoccupation with food; *hunger:* craving as a physiological state. ±: plus-minus sign.

* Indicates significant difference compared to CONT (p ≤ 0.04).

* Indicates significant difference compared to EXT (p ≤ 0.05).
Wellness Questionnaire and Profile of Mood States

As shown in Table 3.3, the wellness questionnaire indicated that fatigue was higher for RES compared to all other trials post-SM (p ≤ 0.02). Also, post-SM sleep quality was higher for CONT and RES compared to FRAG (p = 0.01), and for RES compared to EXT (p = 0.05). General muscle soreness was higher for RES compared to EXT at post-SM (p = 0.02); while stress was higher for EXT compared to CONT and RES (p ≤ 0.02). The recorded total scores for wellness were lower post-SM for RES and FRAG indicating greater TMD compared to CONT and EXT (p ≤ 0.05). Post-EX fatigue remained higher for RES compared to CONT and EXT (p ≤ 0.05). Whereas, post-EX total scores for wellness remained lower for FRAG compared to EXT only (p = 0.03). There was no trial × time interaction for the mood subscale (p = 0.98).

The POMS results are also presented in Table 3.3 and indicate that for RES, fatigue was higher post-SM compared to all other trials and higher in FRAG compared to CONT and EXT (p ≤ 0.05). Post-SM confusion for RES was higher compared to all other trials (p ≤ 0.05) and anger was higher compared to CONT (p = 0.03). Conversely, post-SM vigour for RES was lower compared to EXT (p = 0.03) and for FRAG was lower compared to CONT (p = 0.01). Post-SM TMD for RES and FRAG were higher than CONT and EXT (p ≤ 0.05). Post-EX fatigue remained higher for RES and FRAG compared to EXT (p ≤ 0.04). Post-EX confusion was higher for RES compared to CONT and EXT (p ≤ 0.03); and higher for FRAG compared to EXT (p = 0.05). Also, post-EX vigour scores remained lower for RES compared to EXT (p = 0.02); but only post-EX TMD was higher for FRAG compared to EXT (p = 0.02). There was no time × trial interaction for tension, depression or esteem-affect subscales (p > 0.05). Although, there was a main effect of time for tension with a decrease from post-SM to post-EX (p = 0.01).
### Table 3.3 Wellness and Profile of Mood States post-sleep manipulation (post-SM) and post-exercise (post-EX) following three nights normal sleep (CONT), sleep restriction (RES), sleep extension (EXT) and sleep fragmentation (FRAG) (Mean ± SD; n = 9).

<table>
<thead>
<tr>
<th>Wellness Questionnaire</th>
<th>CONT</th>
<th>Post-EX</th>
<th>RES</th>
<th>Post-EX</th>
<th>EXT</th>
<th>Post-EX</th>
<th>FRAG</th>
<th>Post-EX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatigue</td>
<td>3.2 ± 0.7</td>
<td>2.9 ± 0.8</td>
<td>2.0 ± 0.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.2 ± 0.44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.3 ± 0.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.2 ± 1.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.7 ± 0.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.6 ± 0.9</td>
</tr>
<tr>
<td>Sleep Quality</td>
<td>3.7 ± 0.7</td>
<td>3.9 ± 0.8</td>
<td>3.2 ± 1.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.7 ± 0.9&lt;sup&gt;ab&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General Muscle Soreness</td>
<td>3.6 ± 0.5</td>
<td>3.1 ± 0.9</td>
<td>2.9 ± 0.9</td>
<td>2.8 ± 1.3</td>
<td>3.6 ± 0.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.1 ± 0.9</td>
<td>3.3 ± 0.5</td>
<td>3.2 ± 1.0</td>
</tr>
<tr>
<td>Stress Levels</td>
<td>3.2 ± 0.4</td>
<td>3.4 ± 0.5</td>
<td>2.8 ± 1.1</td>
<td>2.8 ± 1.0</td>
<td>3.8 ± 0.7&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>3.8 ± 0.7</td>
<td>3.2 ± 0.6</td>
<td>3.6 ± 0.7</td>
</tr>
<tr>
<td>Mood</td>
<td>4.1 ± 0.3</td>
<td>4.1 ± 0.6</td>
<td>3.6 ± 0.5</td>
<td>3.5 ± 0.9</td>
<td>4.2 ± 0.4</td>
<td>4.1 ± 0.3</td>
<td>3.6 ± 0.7</td>
<td>3.6 ± 0.5</td>
</tr>
<tr>
<td>Total Mood Disturbance</td>
<td>17.8 ± 1.6</td>
<td>17.2 ± 1.9</td>
<td>15.1 ± 1.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15.5 ± 3.1</td>
<td>18.1 ± 1.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>17.3 ± 2.3</td>
<td>15.4 ± 2.2&lt;sup&gt;ac&lt;/sup&gt;</td>
<td>15.6 ± 2.7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Profile of Mood States</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension</td>
<td>1.7 ± 2.1</td>
<td>1.1 ± 1.3&lt;sup&gt;*&lt;/sup&gt;</td>
<td>4.0 ± 4.6</td>
<td>4.1 ± 6.0&lt;sup&gt;*&lt;/sup&gt;</td>
<td>2.2 ± 2.9</td>
<td>1.0 ± 1.1&lt;sup&gt;*&lt;/sup&gt;</td>
<td>3.1 ± 3.4</td>
<td>1.4 ± 1.6&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td>Depression</td>
<td>0.1 ± 0.3</td>
<td>0.2 ± 0.4</td>
<td>1.4 ± 1.6</td>
<td>2.3 ± 5.7</td>
<td>0.3 ± 0.5</td>
<td>0.2 ± 0.4</td>
<td>1.9 ± 3.0</td>
<td>0.9 ± 2.0</td>
</tr>
<tr>
<td>Anger</td>
<td>0.4 ± 0.7</td>
<td>0.0 ± 0.0</td>
<td>1.9 ± 2.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.3 ± 5.6</td>
<td>0.7 ± 2.0</td>
<td>0.1 ± 0.3</td>
<td>1.4 ± 2.5</td>
<td>1.2 ± 1.9</td>
</tr>
<tr>
<td>Fatigue</td>
<td>2.3 ± 2.7</td>
<td>5.9 ± 3.2</td>
<td>10.4 ± 5.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.4 ± 5.1</td>
<td>2.2 ± 1.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.9 ± 2.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.2 ± 4.1&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>6.1 ± 4.0&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Confusion</td>
<td>1.6 ± 2.0</td>
<td>1.7 ± 2.1</td>
<td>6.3 ± 5.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.3 ± 4.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.3 ± 2.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.2 ± 2.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.0 ± 2.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.2 ± 3.2&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Vigour</td>
<td>7.4 ± 3.4</td>
<td>6.4 ± 3.5</td>
<td>4.7 ± 4.2</td>
<td>5.4 ± 4.0</td>
<td>7.6 ± 3.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.2 ± 4.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.3 ± 4.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.3 ± 4.1</td>
</tr>
<tr>
<td>Esteem-affect</td>
<td>14.8 ± 3.0</td>
<td>14.9 ± 2.6</td>
<td>13.7 ± 3.1</td>
<td>14.7 ± 3.3</td>
<td>14.2 ± 2.9</td>
<td>14.0 ± 3.2</td>
<td>12.6 ± 4.0</td>
<td>13.2 ± 3.2</td>
</tr>
<tr>
<td>Total Mood Disturbance</td>
<td>-16.1 ± 8.8</td>
<td>-12.4 ± 8.3</td>
<td>5.7 ± 14.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.4 ± 23.8</td>
<td>-14.0 ± 7.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-14.8 ± 6.8</td>
<td>-3.2 ± 18.3&lt;sup&gt;ac&lt;/sup&gt;</td>
<td>-7.7 ± 11.2&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>n</sup>: number of participants; ±: plus-minus sign.
<sup>a</sup> Indicates significant difference compared to CONT (p ≤ 0.05).
<sup>b</sup> Indicates significant difference compared to RES (p ≤ 0.05).
<sup>c</sup> Indicates significant difference compared to EXT (p ≤ 0.05).
<sup>*</sup> Indicates main effect of time for all conditions (p ≤ 0.01).
Discussion

This study investigated the effects of normal sleep, RES, FRAG and EXT on appetite and mood among middle-aged, inactive men. A second aim was to determine the effect of vigorous exercise on appetite and mood-related variables following sleep manipulation. The novelty of this study was the integration of appetite and mood responses to sleep loss and extension; and the assessment of vigorous exercise as a potential mediator of appetite- and mood-related responses after sleep loss. Overall, RES and FRAG induced detrimental physiological and perceptual responses compared to CONT and EXT. Interestingly, RES appeared to have a greater effect on increasing acylated ghrelin and decreasing PYY_total levels, leading to an increased desire to eat, prospective food consumption and cravings for sweet foods. FRAG tended to induce poorer mood and perceptual outcomes, including heightened fatigue, general muscle soreness and stress, and poor sleep quality. While EXT did not induce additional benefits compared to CONT for appetite or mood, fatigue was lower compared to RES; however, stress was reportedly higher compared to CONT and RES. Further, acylated ghrelin (orexigenic signal) was higher for EXT compared with CONT and FRAG after the exercise protocol. As such, vigorous exercise did appear to transiently mitigate the increased appetite drive and negative mood responses observed after prolonged RES.

The elevated acylated ghrelin, lower anorexigenic PYY_total levels and higher reported desire to eat observed after three days of RES concurs with previous evidence (Brondel et al., 2010; Magee et al., 2009; Spiegel et al., 2004b). Research has predominantly focused on the responses of ghrelin and leptin to RES; however, the lower PYY_total value following RES in the current study suggests that sleep loss may also downregulate other anorexigenic signals, perhaps to further aid the drive for increased food intake. The hormone changes observed in the current study following RES were associated with an increased desire to eat, desire for sweet foods, and prospective food consumption. It is plausible that the peripheral hormones are the initial respondents to sleep loss, signalling the brain to stimulate feeding to reduce impending fatigue and tiredness (i.e. psychological distress) and cope with extended
wake periods (Chaput, 2014). Furthermore, neuroimaging studies have indicated that brain regions, including the putamen, nucleus accumbens, thalamus, insula, and prefrontal cortex, which process the rewarding quality of foods, become more sensitive to food stimuli when sleep deprived (St-Onge et al., 2012a), particularly for unhealthy compared to healthy food items (St-Onge et al., 2014).

While the observed appetite-related differences following RES compared to the other sleep trials indicate a detrimental effect of sleep loss on appetite, it appears that 20 min of vigorous aerobic exercise may attenuate some of these negative effects. For instance, the downward trend of acylated ghrelin from post-sleep manipulation to post-exercise for CONT, FRAG and RES suggests that exercise is beneficial for appetite responses in general, regardless of prior sleep conditions. However, the slight increase in acylated ghrelin from post-sleep manipulation to post-exercise for the EXT trial indicates that extended sleep may be detrimental for exercise-induced appetite responses which is contrary to our hypothesis. Previous studies which have investigated exercise effects on appetite independent to effects of sleep have reported similar hormone and perceptual changes after exercise to that observed during the CONT, FRAG and RES trials with significant reductions in acylated ghrelin and post-exercise energy intake for up to 24 h (Panissa et al., 2016; Sim et al., 2014). However, these previously reported changes from pre- to post-exercise appear to be larger compared to those observed in the current study, suggesting that sleep loss dampens the exercise-induced downregulation of appetite. Nonetheless, given that exercise had the tendency to suppress appetite for RES, it is plausible that exercise may mediate some compensatory increases in energy intake that are associated with sleep loss.

Mood and wellness were also negatively affected by both sleep loss trials; however, it appeared that FRAG worsened several mood outcomes to a greater extent than RES. Like previous research, participants reported an increase in fatigue, general muscle soreness and stress, and reduced sleep
quality, vigour and esteem-affect following FRAG (Finan et al., 2015; Lentz et al., 1999). When accounting for similar increases in negative mood, Finan et al. (2015) observed a significant reduction in positive mood for FRAG compared to RES. The authors proposed that these mood changes resulted due to a larger reduction in SWS that occurred during the FRAG trial (Finan et al., 2015). Also, Lentz et al. (1999) observed reductions in musculoskeletal pain threshold and reports of increased discomfort, tiredness and fatigue, and reduced vigour when SWS was deprived for three consecutive nights. Despite not measuring sleep stages in the current study, it is possible that the observed changes in mood and wellness were due to a reduction in SWS during FRAG as sleep cycles were purposefully interrupted approximately every two hours.

While both sleep loss trials induced greater negative mood states, highest reported stress was observed for EXT. This result is contrary to previous literature which has reported improvements in mood and wellbeing, particularly decreased fatigue and increased vigour (Kamdar et al., 2004; Mah et al., 2011). The discrepancy between studies is likely due to the age differences between participants in which mean age of the current cohort was 44 y and for Kamdar et al. (2004) and Mah et al. (2011) participants were ≤ 20 y. Also, the actigraphy data from the present study confirm that participants attempted to sleep for the required 10 h during EXT; however, TST indicated that participants only achieved 8 h. Several reasons may have contributed to this observation, including participants obtaining required sleep prior to the scheduled 10 h sleep period (Hirshkowitz et al., 2015); and due to the likelihood of participants having greater economic and domestic responsibilities compared to younger counterparts, leading to increased stress while awake during time in bed pre-empting day-to-day responsibilities (Elo, Leppänen, & Jahkola, 2003).

The novel aspect of the present study is that an inactive, middle-aged population group was recruited to compare the effects of RES, FRAG and EXT on appetite regulation and mood states. Nonetheless,
there were several considerations which need to be acknowledged and may assist the direction for future research. Firstly, a primary aim of this study was to observe appetite and mood responses to sleep conditions which better reflect ‘real world living environments’; therefore, abstinence from alcohol and caffeine were not enforced until the 24 h prior to experimental laboratory procedures. It is possible that the consumption or non-consumption of these substances outside of laboratory conditions may have influenced findings but reveal a more authentic response to sleep manipulation. Despite participants being instructed and attempted to (as shown by TIB) sleep for 10 h per night for EXT, participants were unable to attain this duration, perhaps due to obtaining sleep needs. Also, due to recruitment and logistical constraints testing needed to be completed in the morning; however, afternoon testing may result in greater changes in exercise performance, hormone patterns and mood responses due to diurnal hormone variations and extended daytime wakefulness.

In conclusion, consecutive days of sleep curtailment induces detrimental appetite and mood responses. However, it appeared that shortening sleep duration stimulated an increase in orexigenic signals and cravings for sweet foods which may increase the risk of food overconsumption. Whereas, disruption of sleep continuity tended to induce poor mood states, including increased fatigue and stress. Nonetheless, short-duration, vigorous exercise may mitigate these poor appetite and mood responses and blunt the potential compensatory increase in energy intake (particularly sweet foods). Furthermore, the lack of additional appetite and mood responses observed following EXT suggests that health interventions for inactive, middle-aged men should focus on improving sleep continuity rather than extended sleep duration per se.
Chapter Four: High-intensity interval exercise induces greater acute changes in sleep, appetite-related hormones, and free-living energy intake than does moderate-intensity continuous exercise

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Title: High-intensity interval exercise induces greater acute changes in sleep, appetite-related hormones and free-living energy intake compared to moderate-intensity continuous exercise

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Abstract
The aim of this study was to compare the effect of high-intensity interval and moderate-intensity continuous exercise on sleep characteristics, appetite-related hormones and eating behaviour. 11 overweight, inactive men completed two consecutive nights of sleep assessments to determine baseline (BASE) sleep stages and arousals recorded by polysomnography (PSG). On separate afternoons (1400 - 1600 h), participants completed a 30 min exercise bout: 1) moderate-intensity continuous exercise (MICE; 60 % \( \dot{V}O_2 \text{peak} \)) or 2) high-intensity interval exercise (HIIE; 60 s work at 100 % \( \dot{V}O_2 \text{peak} \): 240 s rest at 50 % \( \dot{V}O_2 \text{peak} \)), in a randomised order. Measures included appetite-related hormones (acylated ghrelin, leptin, peptide tyrosine tyrosine) and glucose pre-exercise, 30 min post-exercise, and the next morning post-exercise; PSG sleep stages, actigraphy (sleep quantity and quality), and self-reported sleep and food diaries were recorded until 48 h post-exercise. There were no between-trial differences for time in bed (\( p = 0.19 \)) or total sleep time (\( p = 0.99 \)). For HIIE, stage N3 sleep was greater (21 ± 7 %) compared to BASE (18 ± 7 %; \( p = 0.02 \)). Also, number of arousals during rapid eye movement sleep were lower for HIIE (7 ± 5) compared to BASE (11 ± 7; \( p = 0.05 \)). Wake after sleep onset was lower following MICE (41 min) compared to BASE (56 min; \( p = 0.02 \)). Acylated ghrelin was lower and glucose higher at 30 min post-exercise for HIIE compared to MICE (\( p \leq 0.05 \)). There were no significant differences in total energy intake between conditions (\( p \geq 0.05 \)). HIIE appears more beneficial than MICE for improving sleep quality and inducing favourable transient changes in appetite-related hormones in overweight, inactive men. However, energy intake was not altered regardless of exercise intensity.

Keywords: Acute exercise, high-intensity intermittent exercise, sleep stages, polysomnography, appetite regulation, appetite behaviour
Introduction

Sleep is an essential physiological occurrence required for optimal cognitive performance and metabolic functioning (Alhola & Polo-Kantola, 2007; Spiegel et al., 2004b). Nevertheless, at least one third of adults do not achieve sleep recommendations (i.e. 7-9 h per night) (Hirshkowitz et al., 2015), in part due to increasing work demands and domestic responsibilities (Bei et al., 2016; Rajaratnam & Arendt, 2001). These chronic reductions in sleep quantity are associated with alterations in the circadian rhythms of key regulatory hormones resulting in increased body mass, impaired metabolism, altered calorie intake, and perception of appetite (Lauderdale et al., 2006; McNeil et al., 2017; Nedeltcheva et al., 2009; Watanabe, Kikuchi, Tanaka, & Takahashi, 2010). Furthermore, sleep quality as determined by the proportion of stage N3 sleep (i.e. deep sleep), rapid eye movement (REM) sleep, and sleep continuity (Adams et al., 2017; Copinschi et al., 2014) appears to decline with age (Alves et al., 2011). Given that exercise is believed to promote sleep quality, it is plausible that age-associated effects on sleep may be dampened following exercise; however, much of the previous literature has recruited young adults with minimal sleep complaints (Youngstedt, 2005). Therefore, the effects of exercise on sleep patterns in middle-aged to older adults remains unclear.

Regular exercise, irrespective of exercise intensity or mode, has been shown to modestly increase sleep duration, stage N3 sleep and REM onset latency (Youngstedt, 2005). Independently, exercise also enhances appetite regulation (Martins et al., 2008) and sensitivity to the signalling of orexigenic and anorexigenic hormones (Dyck, 2005). However, there is ongoing interest regarding the specific exercise intensity that is most beneficial for both sleep and appetite responses (Broom et al., 2009; Dworak et al., 2008; Hayashi et al., 2014; Sim et al., 2014). Previous examinations suggest that adolescents and young adults experience an increase in stage N3 sleep and reductions in sleep onset latency (SOL) and wake after sleep onset (WASO) following high-intensity exercise (Kredlow et al., 2015), while the effect of this exercise intensity on sleep outcomes in middle-aged populations is
largely unexplored. For appetite, high-intensity exercise has been associated with the downregulation of orexigenic signals (e.g. acylated ghrelin) and upregulation of anorexigenic signals (e.g. leptin, peptide tyrosine tyrosine: PYY, and glucose) which may lead to reduced perceived hunger and energy intake in overweight, inactive men for up to 24 h compared to moderate-intensity exercise (Sim et al., 2014). However, the effect of these differing exercise intensities on sleep and appetite have not been examined concurrently. This is important given that shifts in sleep may alter the amplitude and circadian variation of appetite hormones, such as leptin and ghrelin (Copinschi et al., 2014; Spiegel et al., 2004b). For instance, acute sleep restriction (e.g. 4 - 5.5 h per night) has been linked to elevations in circulating ghrelin and reduced levels of leptin leading to increased feelings of hunger and desire for calorie-dense foods (Spiegel et al., 2004b) and overall energy intake (Nedeltcheva et al., 2009).

To date, previous literature has focused on the association between sleep and appetite regulation (Magee et al., 2009; Nedeltcheva et al., 2009; Spiegel et al., 2004b; St-Onge et al., 2012b); acute exercise effects on sleep quality and quantity (Kredlow et al., 2015); or acute exercise effects on appetite regulation (Holliday & Blannin, 2017; Panissa et al., 2016; Sim et al., 2014). Given the multi-directional relationship between these three factors, it is important to investigate the potential simultaneous effects of exercise on sleep and appetite. Hence, the aim of this study was to compare the effect of high-intensity interval exercise (HIIE) and traditional moderate-intensity continuous exercise (MICE) on sleep characteristics, appetite-related hormones and free-living energy intake in inactive, middle-aged men. It was hypothesised that both exercise intensities would improve sleep duration and quality compared to a resting baseline, but HIIE would be more beneficial to sleep (increased stage N3 sleep and reduced arousals) and appetite parameters (anorexigenic changes in the circulating hormones and reduced energy intake) compared to MICE.
Methods

Participants

Eleven overweight, inactive men (mean ± SD; age: 49 ± 5 y; BMI: 28 ± 3 kg·m\(^{-2}\); waist-to-hip ratio (WHR): 0.92 ± 0.05; VO\(_{2}\)\text{peak}: 34 ± 8 ml·kg\(^{-1}\)·min\(^{-1}\)) completed this study. Initially, 13 men volunteered to participate in the study; however, one participant was excluded due to signs of sleep apnoea and one participant withdrew due to illness unrelated to the study. Inclusion/exclusion criteria included non-smokers, participating in < 150 min of moderate-intensity exercise per week, no previous or current diagnosis of sleep or metabolic disorders, and no medical conditions or medications that affect sleep quality or quantity. Sleep was initially assessed by the STOP-BANG questionnaire (Chung et al., 2008) and the Epworth Sleepiness Scale (Johns, 1991). In accordance with Chung et al. (2008) and Johns (1991), scores of 5 - 8 for the STOP-BANG questionnaire and 16 - 24 for the Epworth Sleepiness Scale were indicative of high risk OSA and excessive sleepiness, respectively. Risk of sleep apnoea was further assessed by two consecutive nights of polysomnography (PSG) sleep studies. Medical clearance was obtained from a General Practitioner and a Pre-Exercise Medical Health Questionnaire was completed by each participant prior to participating in the study to ensure no underlying conditions would be exacerbated by vigorous exercise. The study was approved by the Institution’s Human Ethics Committee and written informed consent was attained from all participants prior to data collection.

Experimental Overview

Participants attended the laboratory for an initial familiarisation session and baseline assessments of anthropometry and peak oxygen consumption (VO\(_{2}\)\text{peak}). Habitual sleep and eating patterns were also documented for 7 days and nights (refer to Figure 4.1). During this time, the two consecutive nights of PSG sleep assessments were conducted to exclude sleep apnoea and determine baseline sleep staging and arousals. Following baseline, participants completed two experimental trials (4 days in
duration each) in a randomised order. The experimental trials included either 30 min of moderate-intensity continuous exercise (MICE; 60 % \( \dot{V}O_{2\text{peak}} \)) or 30 min of high-intensity interval exercise (HIIE; 60 s at 100 % \( \dot{V}O_{2\text{peak}} \); 240 s at 50 % \( \dot{V}O_{2\text{peak}} \)). The total mechanical work performed for each exercise protocol was matched (Sim et al., 2014). Experimental trials were performed at the same time of day, with a minimum of 5 days between visits. Primary outcome measures included post-exercise sleep quality and quantity, changes in plasma concentrations of appetite-related hormones, ratings of perceived appetite, and post-exercise free-living energy intake.

**Familiarisation and Baseline Testing**

The familiarisation session involved assessment of height and body mass to calculate body mass index (BMI), and waist and hip girths to calculate waist-to-hip ratio (WHR). In addition, \( \dot{V}O_{2\text{peak}} \) was assessed using a ramp protocol (Barstow, Jones, Nguyen, & Casaburi, 2000) on a stationary cycle ergometer (Lode B.V., Excalibur Sport, Groningen, The Netherlands) to calculate workloads for the experimental trials. The \( \dot{V}O_{2\text{peak}} \) test commenced at 50 W for the first 2 min and increased 25 W every minute thereafter with cadence maintained at 70 rpm until volitional exhaustion. During the test, heart rate (HR; F1, Polar, Electro-Oy, Kempele, Finland) was monitored every minute and breath-by-breath pulmonary gas exchange was obtained via a mouthpiece connected to a calibrated metabolic gas oxygen analysis system and custom-developed software (LabVIEW; National Instruments, Austin, TX, USA).
Figure 4.1 Overview of the experimental procedures. *MICE*: moderate-intensity continuous exercise; *HIIE*: high-intensity interval exercise; *PSG*: polysomnography; $\dot{V}O_{2peak}$: peak oxygen consumption.
Baseline at-home testing was completed for a total of 7 days and nights at which time participants were fitted with a wrist actigraph (Actiware 2, Philips Respironics, Andover, MA), and documented sleep and food intake in a diary provided for the duration of baseline testing. During this time, participants were instructed to maintain usual bedtime, wake-up time, and diet. These data were obtained to provide a representation of habitual sleep quantity and diet given the day-to-day variations associated with these factors (Bei et al., 2016; Champagne et al., 2013). The two PSG sleep studies using a level II, take home PSG device were conducted during the 7 night baseline period to exclude sleep disorders and record baseline sleep stages and arousals.

**Experimental Trials**

During each experimental trial, participants did not engage in physical activity and documented all food and drink consumption 24 h prior to exercise. On the day of exercise, participants abstained from alcohol and caffeine; and fasted for 3 h before arriving to the laboratory between 1400 - 1600 h. Upon arrival, participants were asked to indicate perceived hunger and fullness on validated Visual Analogue Scales (VAS) (Flint et al., 2000) and a capillary blood sample was obtained from the fingertip for the assessment of appetite-related hormones and glucose. Participants then performed the 30 min MICE protocol or HIIE protocol. Exercise was performed on a stationary cycle ergometer (Wattbike Trainer, Wattbike Ltd, Nottingham, UK) and intensity was monitored via power output (PO) and HR (F1, Polar, Electro-Oy, Kempele, Finland) responses every minute. Participants also reported rating of perceived exertion (RPE; 1 - 10 scale) (Borg, 1982) every 5 min. Immediately post-exercise, participants were instructed to sit quietly for 30 min after which time a second blood sample was obtained and perceived appetite was recorded to assess the acute exercise effects on appetite variables. Following exercise, nocturnal sleep was recorded using a level II, take home PSG device and scored for sleep stages and arousals (details below). Participants returned to the laboratory the following morning (within 60 min after waking), for a fasted capillary blood sample and reported perceived appetite to examine appetite
variables in relation to the preceding night’s sleep. Actigraphy, and sleep and food records were maintained for 3 days during each trial, including the day of exercise, one day after exercise, and two days after exercise (refer to Figure 4.1). Data were examined for sleep quantity and energy intake up to 48 h post-exercise. Following exercise, participants were free to choose bed times, wake-up times, and food intake to observe sleep and eating responses to the respective trials.

Polysomnography

Polysomnography was performed using recommended electrode and sensor placements (Berry et al., 2016), connected to an Alice PDx system (Philips Respironics, Pittsburg, USA) and analysed using Sleepware G3 software version 3.7.4 (Philips Respironics, Pittsburg, USA). Electrode and sensor placements included: three electroencephalogram (EEG; F3-A2, C4-A1, and O1-A2) electrodes, unilateral electrooculogram (EOG), chin electromyography (EMG), electrocardiography (ECG; lead I), oxygen saturation via pulse oximetry, thoracic and abdominal respiratory effort via belts, and nasal airflow via pressure transducer. The baseline sleep studies were scored to exclude sleep disorders and data were used for the baseline sleep staging and arousal parameters. Sleep studies during experimental trials were only assessed for sleep staging and arousals. All sleep studies were scored using standard guidelines (Berry et al., 2016) by an experienced sleep technician who was blinded to the experimental trials. Sleep parameters assessed included time in bed, total sleep time (TST), sleep efficiency (SE) \([\text{sleep duration - wake time} / \text{sleep duration} \times 100]\), sleep onset latency (SOL: time from lights out to the first epoch of sleep), rapid eye movement (REM) onset latency, wake after sleep onset (WASO: total time awake after sleep onset), percent of time spent in each sleep stage (N1: stage 1; N2: stage 2; N3: stage 3; NREM: non-rapid eye movement sleep; REM), and number of arousals (NREM, REM and total arousals).
Actigraphy

Actigraphy was recorded in 1 min epochs (Esliger & Tremblay, 2006) and analysed using Actiware v5.70 software (Philips Respironics, Pittsburgh, USA). Variables obtained included bed time, wake-up time, time in bed (period between bed time and wake time), TST (time asleep during time in bed), SOL (period between bed time and sleep onset), SE (percent of time in bed spent sleeping), WASO (total time awake after sleep onset), and number of awakenings (Knutson et al., 2007a).

Appetite Perception and Hormones

Perceived hunger and fullness were assessed using a VAS comprised of straight lines (100 mm) accompanied by a question anchored with words representing opposing extreme states of hunger and fullness at either end (Flint et al., 2000). A 600 μl blood sample was obtained from a fingertip using a sterile lancet. To assist vasodilation, the hand was submerged in a bowl of warm water for 5 min prior to blood draw. Blood glucose concentration was measured directly from the fingertip using an Accu-Chek Performa (Roche, Manheim, Germany). The remaining blood was immediately aliquoted into pre-chilled EDTA tubes (Becton Dickinson, Sydney, Australia) treated with serine protease inhibitor (25 μl per 600 μl of blood; Pefabloc® SC, Sigma-Aldrich, St. Louis, USA) then centrifuged at 3000 rpm for 10 min. Plasma obtained was stored at -80 °C and later analysed according to manufacturer’s instructions for acylated ghrelin, leptin and peptide tyrosine tyrosine (PYY\textsubscript{total}) using a commercially available assay kit (Milliplex, Millipore Corporation, MA, USA). These hormones were chosen due to their role in hunger and satiety signalling, responsiveness to exercise (Balaguera-Cortes et al., 2011; Broom et al., 2009) and association with sleep changes (Spiegel et al., 2011). For acylated ghrelin, leptin and PYY\textsubscript{total} the intra- and inter-assay coefficient of variations were < 10 % and < 15 %.
Sleep and Energy Intake Records

A self-reported diary for sleep, and food and drink intake, was provided to participants. Sleep records were used to confirm bed time and wake-up time for actigraphy data. For food records, instructions on the use (including a 1 day example), and the necessity for accurate (i.e. food and drink brands and quantities) and detailed recordings of energy intake immediately after consumption were emphasised. Total energy and macronutrient intake were calculated using commercially available software (Foodworks; Xyris Software, Kenmore Hills, QLD, Australia). Also, absolute (g) and relative data (%) were calculated for carbohydrate, fat and protein intake.

Statistical Analysis

A *priori* sample size calculations for a repeated measures ANOVA was performed using G*Power* (version 3.1.9.2) which confirmed that a sample size of 8 would provide an actual power of 94 %, therefore the final sample size of 11 was adequate for the input parameters (Nilius et al. 2017). Order effect analysis was also completed and indicated no significant difference between trial 1 and trial 2 for PSG total sleep time or wake after sleep onset (p ≤ 0.14); however, sleep efficiency was significant (p = 0.006). A repeated measures (trial × time interaction) ANOVA with Tukey’s LSD *post hoc* were used to compare physiological and perceptual measures, perceived appetite, appetite-related hormones and glucose, total and macronutrient energy intake, PSG and actigraphy variables between trials. PSG data were further separated to analyse the initial 180 min after sleep onset as the first 1 - 2 sleep cycles have been shown to be altered by acute stimuli including high-intensity exercise (Myllymäki et al., 2012; Netzer et al., 2001). For total and macronutrient energy intake, two analyses were conducted to compare the difference between MICE and HIIE immediate post-exercise (i.e. acute: energy intake for the remainder of the day following exercise) and to compare differences between BASE, MICE and HIIE (i.e. over the total 48 h period of monitoring). Analyses were performed
using Statistical Package for Social Sciences (SPSS v 20.0, Chicago, USA). Data are reported as mean ± standard deviation (SD) and statistical significance was accepted at p ≤ 0.05.

Results

Exercise Characteristics

The mean heart rate for MICE and HIIE were 126 ± 10 bpm and 132 ± 10 bpm, respectively. Heart rate responses during HIIE were higher compared to MICE at 1 - 6, 10 - 11 min, 15 - 16 min, 20 - 21 min, 25 - 26 min, and 30 min (p ≤ 0.04; Figure 4.2A). Mean RPE was significantly lower for MICE (3 ± 1) compared to HIIE (7 ± 2; p = 0.001; Figure 4.2B). Higher RPE was reported following all HIIE sprint intervals compared to the corresponding times for MICE (p ≤ 0.001; Figure 4.2B).
Figure 4.2 Mean ± SD A. heart rate; and B. rating of perceived exertion during 30 min of moderate-intensity continuous exercise (MICE) and high-intensity interval exercise (HIIE) (n = 11).

*b Indicates significant trial × time interaction between MICE and HIIE (p ≤ 0.04).
Polysomnography and Actigraphy

Whole night and initial 180 min polysomnography data are presented in Table 4.1. There were no significant differences for time in bed, total sleep time, sleep efficiency, sleep onset latency, or N1, N2, NREM and REM sleep between BASE, MICE and HIIE (p > 0.05). However, there was a significant decrease in wake after sleep onset following MICE compared to BASE (p = 0.02). Also, the proportion of N3 sleep was higher (p = 0.02), while the number of arousals were lower during REM sleep (p = 0.05) for HIIE compared to BASE. There were no differences for NREM arousals (p = 0.59) or total arousals between BASE, MICE or HIIE (p = 0.64). When the initial 180 min PSG was considered, the proportion of NREM sleep was higher and REM sleep was lower after HIIE compared to BASE (p = 0.02). The number of arousals during REM sleep was also decreased for HIIE compared to BASE (p = 0.03). There were no differences for NREM arousals (p = 0.21) or total arousals between BASE and both exercise trials (p = 0.36). There were no between-trial differences for all other sleep parameters assessed (p > 0.05).

Actigraphy data indicated time in bed was longer the night after MICE compared to HIIE (p = 0.02), however, there was no significant differences between trials for any other actigraphy variables (p > 0.05).
Table 4.1 Mean ± SD whole night and initial 180 min sleep data for baseline (BASE), after moderate-intensity continuous exercise (MICE) and high-intensity interval exercise (HIIE) trials (n = 11).

<table>
<thead>
<tr>
<th></th>
<th>BASE Whole Night</th>
<th>BASE Initial 180 min</th>
<th>MICE Whole Night</th>
<th>MICE Initial 180 min</th>
<th>HIIE Whole Night</th>
<th>HIIE Initial 180 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time in bed (min)</td>
<td>484.6 ± 39.8</td>
<td>473.2 ± 31.2</td>
<td>461.7 ± 34.9</td>
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<tr>
<td>Total sleep time (min)</td>
<td>405.7 ± 54.4</td>
<td>163.7 ± 14.3</td>
<td>405.1 ± 38.2</td>
<td>168.5 ± 8.0</td>
<td>407.1 ± 40.7</td>
<td>167.5 ± 11.3</td>
</tr>
<tr>
<td>Sleep efficiency (%)</td>
<td>83.7 ± 6.9</td>
<td>90.8 ± 7.9</td>
<td>85.7 ± 6.9</td>
<td>93.4 ± 4.5</td>
<td>88.2 ± 5.6</td>
<td>92.8 ± 6.3</td>
</tr>
<tr>
<td>Sleep onset latency (min)</td>
<td>23.1 ± 16.2</td>
<td>27.4 ± 28.2</td>
<td>18.4 ± 15.2</td>
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<td></td>
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<tr>
<td>Rapid eye movement latency (min)</td>
<td>84.2 ± 21.0</td>
<td>82.9 ± 21.9</td>
<td>107.8 ± 70.6</td>
<td>107.8 ± 70.6</td>
<td>109.5 ± 34.6</td>
<td>109.5 ± 34.5</td>
</tr>
<tr>
<td>Wake after sleep onset (min)</td>
<td>55.7 ± 32.6</td>
<td>16.7 ± 14.2</td>
<td>40.8 ± 21.9(^a)</td>
<td>11.9 ± 8.0</td>
<td>36.2 ± 21.6</td>
<td>13.0 ± 11.3</td>
</tr>
<tr>
<td>Stage N1 sleep (%)</td>
<td>8.4 ± 4.0</td>
<td>6.9 ± 3.4</td>
<td>7.3 ± 1.9</td>
<td>5.2 ± 2.3</td>
<td>6.3 ± 2.3</td>
<td>5.6 ± 3.2</td>
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<tr>
<td>Stage N2 sleep (%)</td>
<td>53.9 ± 5.9</td>
<td>52.8 ± 7.9</td>
<td>54.4 ± 8.9</td>
<td>53.7 ± 10.7</td>
<td>55.5 ± 7.7</td>
<td>55.3 ± 7.9</td>
</tr>
<tr>
<td>Stage N3 sleep (%)</td>
<td>18.0 ± 7.2</td>
<td>27.7 ± 10.6</td>
<td>20.7 ± 6.9</td>
<td>31.2 ± 5.9</td>
<td>21.0 ± 7.3(^a)</td>
<td>31.9 ± 8.2</td>
</tr>
<tr>
<td>Non-rapid eye movement (%)</td>
<td>80.3 ± 3.9</td>
<td>87.3 ± 5.4</td>
<td>82.4 ± 3.9</td>
<td>90.2 ± 6.0</td>
<td>82.8 ± 5.2</td>
<td>92.4 ± 4.2(^a)</td>
</tr>
<tr>
<td>Rapid eye movement (%)</td>
<td>19.7 ± 3.9</td>
<td>12.7 ± 5.4</td>
<td>17.6 ± 3.9</td>
<td>9.8 ± 6.0</td>
<td>17.2 ± 5.2</td>
<td>7.6 ± 4.3(^a)</td>
</tr>
<tr>
<td>Non-rapid eye movement arousals (#)</td>
<td>53.3 ± 22.4</td>
<td>23.2 ± 9.8</td>
<td>58.5 ± 21.7</td>
<td>28.5 ± 10.6</td>
<td>61.3 ± 28.5</td>
<td>31.2 ± 16.2</td>
</tr>
<tr>
<td>Rapid eye movement arousals (#)</td>
<td>10.8 ± 6.8</td>
<td>2.3 ± 1.5</td>
<td>11.2 ± 7.7</td>
<td>3.1 ± 2.8</td>
<td>7.4 ± 4.9(^a)</td>
<td>1.3 ± 1.2</td>
</tr>
<tr>
<td>Total arousals (#)</td>
<td>83.0 ± 30.8</td>
<td>31.5 ± 12.0</td>
<td>89.5 ± 24.9</td>
<td>38.1 ± 14.4</td>
<td>82.4 ± 32.9</td>
<td>37.5 ± 17.5</td>
</tr>
</tbody>
</table>

\(^a\) Indicates significant difference compared to BASE (p ≤ 0.05).
Perceived Appetite and Appetite-Related Hormones

There was no trial x time interaction for perceived hunger (p = 0.29; Figure 4.3A) or fullness (p = 0.73; Figure 4.3B). However, there was a main effect of time for both trials whereby hunger was higher and fullness was lower the morning after-exercise compared with pre-exercise ratings (p ≤ 0.02).

The hormone and glucose responses to MICE and HIIE are shown in Figure 4.4. There was a trial x time interaction for acylated ghrelin, with post hoc analyses revealing significantly higher acylated ghrelin pre-exercise for HIIE compared to MICE (p = 0.001), and lower ghrelin at 30 min post-exercise for HIIE compared to MICE (p = 0.03; Figure 4.4A). There was also a trial x time interaction for glucose, with higher concentrations at 30 min post-exercise for HIIE compared to MICE (p = 0.02; Figure 4.4D). There was no trial x time interaction for leptin or PYY_total (p > 0.05), but there was a main effect of time for leptin with higher concentrations the morning post-exercise compared to 30 min post-exercise (p = 0.05; Figure 4.4B).

Free Living Energy Intake

Energy intake for the remainder of the day after exercise for HIIE (4281 ± 1822 kJ) was lower than MICE (5273 ± 2589 kJ); however, this was not statistically significant (p = 0.55). The contribution of carbohydrate (MICE: 39 ± 12 %; HIIE: 33 ± 14 %; p = 0.09) and protein (MICE: 17 ± 6 %; HIIE: 13 ± 5 %; p = 0.09) to energy intake was similar between trials for the remainder of the day following exercise. In addition, there was no difference in sodium (MICE: 1747 ± 1289 mg; HIIE: 1056 ± 918 mg; p = 0.16) or sugar intake (MICE: 49 ± 45 g; HIIE: 34 ± 30 g; p = 0.10). Likewise, absolute fat intake was similar between trials; however, the proportion of energy intake from fat was higher following HIIE (42 ± 7 %) compared to MICE (34 ± 11 %; p = 0.04) for the remainder of the day following exercise.
Energy and macronutrient intake for BASE, and two days after the day of MICE and HIIE (i.e. day+1 and day+2) are presented in Table 4.2. Relative fat intake for the day following exercise was significantly greater for HIIE compared to MICE (p = 0.03). Absolute carbohydrate intake for MICE on the day of exercise was higher compared to BASE (p = 0.04); but lower at two days post-exercise compared to BASE (p = 0.05). Moreover, relative carbohydrate intake for the day following MICE was higher compared to BASE (p = 0.03); while for two days after exercise, MICE was higher compared to HIIE (p = 0.03). Absolute protein intake was higher on the day of MICE compared to BASE (p = 0.04); while, one day following MICE intake was lower compared to BASE (p = 0.04). On the day of MICE and HIIE, and two days after HIIE, sodium intake was higher compared to BASE (p ≤ 0.03). There were no further trial × time interactions for energy intake (p = 0.61), macronutrient intake (p ≥ 0.07) or caffeine ingestion (p = 0.54). There was a main effect of time for sugar intake, with reduced consumption from the day of exercise until the two days following exercise (p = 0.02).
Figure 4.3  Mean ± SD A. perceived hunger; and B. perceived fullness on the day of exercise (day 0) at pre-exercise and 30 min post-exercise, and the morning after exercise (day 1 morning) for moderate-intensity continuous exercise (MICE) and high-intensity interval exercise (HIIE) (n = 11).

* Indicates a main effect of time for both trials (p ≤ 0.05).
Figure 4.4 Mean ± SD A. acylated ghrelin; B. leptin; C. peptide tyrosine tyrosine (PYY_{total}); and D. glucose on the day of exercise (day 0) at pre-exercise and 30 min post-exercise, and the morning after exercise (day 1 morning) for moderate-intensity continuous exercise (MICE) and high-intensity interval exercise (HIIE) trials (n = 11).

*b* Indicates significant trial × time interaction between MICE and HIIE (p ≤ 0.03).

** Indicates a main effect of time for both trials (p < 0.05).
### Table 4.2 Mean ± SD total energy and macronutrient intake for baseline (BASE), day of moderate-intensity continuous exercise (MICE-0), one day after MICE (MICE+1), two days after MICE (MICE+2), day of high-intensity interval exercise (HIIE-0), one day after HIIE (HIIE+1), two days after HIIE (HIIE+2) (n = 11).

<table>
<thead>
<tr>
<th></th>
<th>BASE</th>
<th>MICE-0</th>
<th>MICE+1</th>
<th>MICE+2</th>
<th>HIIE-0</th>
<th>HIIE+1</th>
<th>HIIE+2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Energy Intake (kJ)</td>
<td>8501 ± 3248</td>
<td>9471 ± 4039</td>
<td>7229 ± 4468</td>
<td>8454 ± 5367</td>
<td>8395 ± 2217</td>
<td>7215 ± 3266</td>
<td>7813 ± 3544</td>
</tr>
<tr>
<td>Carbohydrates (g)</td>
<td>204 ± 84</td>
<td>265 ± 129\textsuperscript{a}</td>
<td>193 ± 119\textsuperscript{a}</td>
<td>140 ± 62</td>
<td>220 ± 93</td>
<td>179 ± 72</td>
<td>190 ± 83</td>
</tr>
<tr>
<td>(%)</td>
<td>41 ± 7</td>
<td>47 ± 13</td>
<td>45 ± 8\textsuperscript{a}</td>
<td>32 ± 15\textsuperscript{b}</td>
<td>43 ± 11</td>
<td>43 ± 6</td>
<td>42 ± 9\textsuperscript{b}</td>
</tr>
<tr>
<td>Fats (g)</td>
<td>78 ± 37</td>
<td>78 ± 37</td>
<td>63 ± 45</td>
<td>74 ± 32</td>
<td>83 ± 29</td>
<td>66 ± 43</td>
<td>61 ± 34</td>
</tr>
<tr>
<td>(%)</td>
<td>34 ± 6</td>
<td>31 ± 9\textsuperscript{b}</td>
<td>33 ± 9</td>
<td>36 ± 11</td>
<td>37 ± 7\textsuperscript{b}</td>
<td>32 ± 10</td>
<td>30 ± 8</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>97 ± 37</td>
<td>115 ± 45\textsuperscript{a}</td>
<td>67 ± 38\textsuperscript{a}</td>
<td>82 ± 43</td>
<td>93 ± 39</td>
<td>79 ± 38</td>
<td>80 ± 45</td>
</tr>
<tr>
<td>(%)</td>
<td>19 ± 3</td>
<td>21 ± 7</td>
<td>16 ± 3</td>
<td>18 ± 7</td>
<td>18 ± 5</td>
<td>18 ± 4</td>
<td>16 ± 4</td>
</tr>
<tr>
<td>Sodium (mg)</td>
<td>2078 ± 349</td>
<td>3357 ± 1789\textsuperscript{a}</td>
<td>2327 ± 1544</td>
<td>1620 ± 858</td>
<td>2658 ± 752\textsuperscript{a}</td>
<td>1985 ± 1372</td>
<td>1680 ± 670\textsuperscript{a}</td>
</tr>
<tr>
<td>Sugar (g)</td>
<td>81 ± 41</td>
<td>114 ± 59</td>
<td>82 ± 66\textsuperscript{*}</td>
<td>63 ± 21\textsuperscript{*}</td>
<td>85 ± 49</td>
<td>66 ± 46\textsuperscript{*}</td>
<td>73 ± 49\textsuperscript{*}</td>
</tr>
<tr>
<td>Caffeine (mg)</td>
<td>146 ± 76</td>
<td>120 ± 62</td>
<td>102 ± 92</td>
<td>151 ± 101</td>
<td>100 ± 91</td>
<td>100 ± 78</td>
<td>125 ± 78</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Indicates significant difference compared to BASE (p ≤ 0.05).
\textsuperscript{b} Indicates significant trial × time interaction between MICE and HIIE (p = 0.03).
\textsuperscript{*} Indicates a main effect of time for MICE and HIIE (p ≤ 0.05).
Discussion

This study investigated the effect of high-intensity interval exercise compared to traditional moderate-intensity continuous exercise on sleep characteristics, appetite responses and subsequent free-living energy intake in overweight, inactive men. The novel design of the study allowed for a simultaneous examination of sleep and appetite responses following two popular exercise modalities. It appears that HIIE induced an increased proportion of stage N3 sleep and total NREM sleep, and reduced REM sleep and arousals during REM sleep compared to BASE; while only lower wake after sleep onset was observed following MICE compared to BASE. Also, circulating acylated ghrelin was lower and glucose concentrations were higher transiently after HIIE compared to MICE, suggesting a favourable hormonal milieu for reduced energy intake. However, these changes were not associated with significant alterations in total energy intake either acutely (i.e. for the remainder of the day following exercise) or chronically (i.e. for the 2 days following exercise). Collectively, these findings indicate that HIIE may have a greater positive influence on sleep and appetite-related hormones compared to MICE. However, the alterations in acute sleep and appetite regulation may not be reflected by changes in perceptual measures (hunger and satiety) or behaviours (sleep hygiene and dietary choices).

The observed changes in sleep following exercise are consistent with previous research that has examined various populations. Specifically, greater stage N3 sleep and improved sleep efficiency have been observed, in conjunction to decreased sleep onset latency, wake after sleep onset and number of arousals (Bunnell et al., 1983; Dworak et al., 2008; Flausino et al., 2012; Hayashi et al., 2014; Horne & Staff, 1983; Passos et al., 2010; Wong et al., 2013). However, several studies have also indicated decreased REM sleep (Flausino et al., 2012; Hayashi et al., 2014; Passos et al., 2010; Wong et al., 2013). In contrast, despite a reduction in REM sleep in the initial 180 min of sleep, there was no difference in REM sleep across the whole night suggesting that after HIIE, a greater proportion of REM sleep was experienced later in the night, compared to baseline sleep. Robey et al. (2013) observed similar
changes in REM sleep following vigorous evening exercise for highly trained cyclists. While the cause of the change in distribution warrants further investigation, Netzer et al. (2001) investigated a potential aminergic effect following intense exercise in highly trained endurance athletes whereby a similar decrease in the proportion of REM sleep in the first half of sleep was observed. The authors reported that an extension of REM onset latency and reduction in REM sleep percentage correlated with an increase of norepinephrine and epinephrine, suggesting that the autonomic nervous system plays a key role in the regulation of REM sleep (Netzer et al., 2001). Nonetheless, further research is required to examine the influence of catecholamine excretion during exercise on subsequent sleep and whether age- and fitness-related factors alter the effects.

A possible explanation for the improved sleep following HIIE may be the increased physiological stress associated with high-intensity exercise compared to moderate-intensity exercise (Burgomaster et al. 2005; Crisp et al., 2012; Helgerud et al., 2007; Wisløff et al., 2007). In contrast to MICE, high-intensity exercise induces rapid increases in heart rate, release of metabolic hormones (e.g. growth hormone), lactate, and depletion of adenosine triphosphate, creatine phosphate and glycogen stores (Boutcher, 2010; Tomlin & Wenger, 2001; Trapp et al., 2007; Weinstein et al., 1998). Consequently, recovery may be extended, and oxygen consumption remains elevated post-exercise to accelerate the return of metabolic processes to a resting state (Boutcher, 2010; Laforgia et al., 2006). Given the vigorous nature of our HIIE protocol, it is plausible that participants experienced greater glycogen depletion and metabolite accumulation which required a longer recovery compared to the MICE trial. Simultaneously, untrained individuals have been shown to experience slower rates of recovery compared to trained counterparts (Børsheim & Bahr, 2003; Gore & Withers, 1990). As such, the deconditioned state of the current cohort may have exacerbated the physiological effects of high-intensity exercise, resulting in an extended recovery time. Given the nature of stage N3 sleep to restore and repair peripheral tissue, it is plausible that the observed increase in stage N3 sleep after
HIIE was associated with a greater need for body restoration, and vital growth and repair (Tasali et al., 2008).

In addition to sleep changes, HIIE induced transient changes in appetite-related hormones and glucose that would appear favourable for reducing energy intake compared to MICE. More specifically, decreased ghrelin and increased glucose were observed 30 min after exercise for the HIIE trial. The lower ghrelin following HIIE occurred despite significantly higher circulating ghrelin prior to exercise, suggesting the magnitude of decrease in ghrelin with HIIE was substantial. The reason for the higher ghrelin prior to the HIIE trial is likely due to biological variation in ghrelin secretion and clearance (King et al., 2017). Given that participants complied with the fasting requirements of this study, the difference in fasting levels may simply reflect the considerable intra- and inter-individual variation of acylated ghrelin despite controlling for energy intake as reported in the literature (King et al., 2017; Spiegel et al., 2011). Furthermore, given that increases in circulating glucose stimulate the release of insulin and act centrally to increase satiety and blunt the food reward response (Flint et al., 2007; Page et al., 2013), the higher glucose response to HIIE compared to MICE may also contribute to a potential downregulation of appetite. The present results are consistent with those of Sim et al. (2014) who observed a significant decline in ghrelin and increase in glucose acutely following high-intensity exercise compared with a bout of traditional moderate-intensity exercise. These responses were observed despite a greater fasting time (overnight 10 h fast) compared to the current study, and exercise being performed in the morning instead of the afternoon. As such, these two studies suggest that high-intensity exercise significantly alters appetite-related hormone concentrations independent of exercise time-of-day.
Despite the abovementioned transient alterations in appetite-related hormones and metabolites, the current study did not observe significant differences in energy intake between the HIIE or MICE trials. Food records did indicate lower total energy intake for the remainder of the exercise day following HIIE compared to MICE; however, this difference was not statistically significant. Sim et al. (2014) observed significant reductions in energy intake for up to 24 h post-exercise following a high-intensity protocol compared to a non-exercise control trial and MICE trial. Similarly, Thivel et al. (2012) observed suppressed energy intake in obese adolescents following vigorous exercise compared to moderate-intensity exercise for up to 24 h post-exercise. However, it is important to note that energy intake at the post-exercise meal was assessed under controlled laboratory conditions in these studies by Sim et al. (2014) and Thivel et al. (2012); whereas, the present study utilised self-reported food diaries which may make the detection of differences in food intake more difficult and may explain the large variation between participants. While overall energy intake was not significantly altered, there was some evidence of changes in macronutrient intake in the current study, such as the reduction of sugar intake in the two days following exercise compared to the day of exercise for both MICE and HIIE. However, these observed changes may simply reflect day-to-day variation which is influenced by many other factors including food availability, food diversity, and social engagements (Champagne et al., 2013), rather than in response to the acute exercise bouts.

The complex neuroendocrine pathways which link sleep and appetite continuously communicate to maintain energy homeostasis (Wynne et al., 2005). As such, when sleep is altered there are sub-sequent changes to the circadian rhythm of appetite-related hormone release which influences dietary and eating behaviour changes (Copinschi et al., 2014; Spiegel et al., 2004b). Given this knowledge, it was important to examine sleep and appetite simultaneously following acute exercise which has been shown to influence both sleep patterns (Robey et al., 2013) and appetite (Sim et al., 2014). Although not all sleep measures were significantly different between trials, trends indicate that
the HIIE trial had a greater positive impact on sleep quality measures compared to MICE, including a
dominance of NREM sleep in the first half of sleep, and a greater proportion of REM sleep in the second
half of sleep (Copinschi et al., 2014; Rama et al., 2005; Sharma & Kavuru, 2010). However, it is
expected that from approximately 35 y of age the duration of stage N3 sleep reduces dramatically
followed by a progressive decline in REM sleep (Copinschi et al., 2014). Given the age of the
participants, it is plausible that age-related factors were influencing baseline sleep. As such, the
increase in stage N3 sleep and redistribution of REM sleep to the latter half of the night after HIIE
suggests that vigorous exercise may slow the rate of age-related sleep changes. Even though we did
not observe a difference in perceived appetite or energy intake, it is possible that the changes in
ghrelin and leptin concentrations over time were positively influenced by sleep regardless of exercise
intensity. Although appetite-related hormones were not measured at baseline, the morning after
exercise results for ghrelin support the notion that there is a sleep-associated inhibition of the
orexigenic signal (Copinschi et al., 2014). Nonetheless, continued research is required to further assess
the link between sleep and appetite following exercise due to the complexity of the neuroendocrine
pathways.

The strength and novel aspect of the current study is the examination of the interaction between three
key areas that is sleep, appetite and exercise. Nonetheless, there are several limitations which need
to be addressed and may assist the direction of future research. There were limited time points for
the analysis of acylated ghrelin, leptin, PYY_{total} and glucose; however, the three designated time points
are in alignment with capturing acute and prolonged responses across all hormones. Additionally, the
accuracy of self-reporting physical activity may have been limited due to the risk of participants under-
or over-reporting exercise duration, type and intensity during the study. As such, future research may
assess physical activity with a combination of accelerometer activity data and self-reported data.
In summary, the key findings of this study are that HIIE induces positive changes in sleep and appetite which would appear favourable for improved sleep quality and reduced energy intake. We suggest that the increase in stage N3 sleep and reduced number of arousals during REM sleep were associated with the high energy demands associated with high-intensity exercise and subsequent need for body restoration. In conjunction, the minimal reduction in energy intake following HIIE may have been a result of the transient reduction of ghrelin and increased glucose concentration; however, these changes were not significant and did not continue during the 48 h post-exercise. Taken together, the acute sleep and appetite responses to high-intensity exercise appear small and transient. Nonetheless, compounding these effects may better assist sleep quality, regulation of metabolic hormones, weight management and eating behaviour over an extended time. As such, future studies may profit from investigating these sleep, appetite and exercise associations further under a chronic setting.
Chapter Five: Evening high-intensity interval exercise does not disrupt sleep or alter energy intake despite changes in acylated ghrelin in middle-aged men

As published in Experimental Physiology

Title: Evening high-intensity interval exercise does not disrupt sleep or alter energy intake despite changes in acylated ghrelin in middle-aged men

Running Title: Evening exercise, sleep and appetite

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Subject Area: Sleep and health
New Findings

• What is the central question of this study?
  o High-intensity interval exercise (HIIE) is recommended to be avoided within 4 h of bedtime due to potential sleep disruptions which may affect appetite-related hormone interactions and subsequent energy intake. Yet, the interactions between sleep and appetite following early evening HIIE has not been previously explored.

• What is the main finding and its importance?
  o We show that HIIE can be performed in the early evening without subsequent sleep disruptions and may favourably alter appetite-related hormone concentrations. Nonetheless, perceived appetite and energy intake do not change with acute HIIE regardless of time-of-day.
Abstract

Many adults remain inactive, despite exercise benefits for sleep and appetite, due to increased time-restraints. Methods to improve exercise compliance include preferential time-of-day or engaging in short-duration, high-intensity interval exercise (HIIE). Hence, this study aimed to compare effects of HIIE time-of-day on sleep and appetite. Eleven inactive men undertook sleep monitoring to determine baseline (BASE) sleep stages and exclude sleep disorders. On separate days, participants completed 30 min HIIE (60 s work at 100 % VO₂peak: 240 s rest at 50 % VO₂peak) in the 1) morning (MORN; 0600 - 0700 h), 2) afternoon (AFT; 1400 - 1600 h) and 3) early evening (EVEN: 1900 - 2000 h). Measures included appetite-related hormones (acylated ghrelin, leptin, peptide tyrosine tyrosine), and glucose pre-exercise, 30 min post-exercise, and next morning; overnight polysomnography (PSG; sleep stages); and actigraphy, self-reported sleep and food diaries for 48 h post-exercise. There were no between-trial differences for total sleep time (p = 0.46). Greater stage N3 sleep was recorded for MORN (23 ± 7 %) compared to BASE (18 ± 7 %; p = 0.02); however, no between-trial differences existed (p > 0.05). Rapid eye movement (REM) sleep was lower and non-REM sleep was higher for EVEN compared to BASE (p ≤ 0.05). At 30 min post-exercise, ghrelin was higher for AFT compared to MORN and EVEN (p = 0.01); while glucose was higher for MORN compared to AFT and EVEN (p ≤ 0.02). No between-trial differences were found for perceived appetite (p ≥ 0.21) or energy intake (p = 0.57). Early evening HIIE can be performed without subsequent sleep disruptions and reduces acylated ghrelin. However, perceived appetite and energy intake appear to be unaffected by HIIE time-of-day.

Keywords: Sleep, vigorous exercise, appetite regulation
Introduction

Regular exercise is believed to be an important behaviour to assist in the improvement of sleep (Buman et al., 2014). However, there has been coincidental reductions in exercise participation and sleep duration in recent decades which is reportedly due to a commonly cited barrier of ‘lacking time’ (Buman et al., 2014; Gibala et al., 2012; Rajaratnam & Arendt, 2001). For example, in Australia peak inactivity occurs at 35 - 54 y of age (ABS, 2015), while 60 - 64 % of this age group also have at least one persistent sleep problem such as not obtaining adequate sleep, feeling unrefreshed upon waking, or waking frequently during the night (Adams et al., 2017). In addition, reduced sleep duration has also played a significant role in the upregulation of the orexigenic hormone acylated ghrelin and downregulation of anorexigenic hormones such as leptin and peptide tyrosine tyrosine (PYY) which is highlighted in acute sleep deprivation studies (Magee et al., 2009; Omisade et al., 2010; St-Onge et al., 2012b). To combat this, short duration, high-intensity interval exercise (HIIE) has been encouraged to increase exercise participation (Gibala et al., 2012). Also, the physiological basis for this type of exercise in relation to sleep and appetite is supported by evidence of increased sleep efficiency and reduced sleep onset latency (Dworak et al., 2008; Hayashi et al., 2014); increased anorexigenic signalling and subsequent reduction of energy intake (Broom et al., 2017; Sim et al., 2014); and higher, longer lasting reductions on post-prandial glucose compared to moderate-intensity exercise (Little et al., 2014).

The American Academy of Sleep Medicine (2001) supports the recommendation of regular exercise to aid sleep; although, it is advised to avoid high-intensity or vigorous exercise close to bed time since this may increase arousal and disrupt subsequent sleep. However, the evidence for this is limited and appears to be a common warning which has come from early exercise and sleep research rather than recommendations that have evolved from more recent research (Irish et al., 2015). Instead, experimental findings indicate that sleep is not disturbed by early evening high-intensity exercise but may improve some variables including sleep efficiency, stage N3 sleep and sleep onset latency.
Chapter 5: Study 3

(Flausino et al., 2012; Hayashi et al., 2014; Myllymäki et al., 2012; O’Connor et al., 1998; Robey et al., 2013; Youngstedt, Kripke, & Elliott, 1999). It has been postulated that the acute body-heating, anxiolytic and antidepressant effects of exercise may, in part, explain these observed sleep changes following evening high-intensity exercise (Youngstedt, 2005). Nevertheless, most studies have recruited young, active adults already obtaining recommended sleep quantity and thus do not represent the age-associated changes in sleep patterns experienced by many middle-aged, inactive adults (Copinschi et al., 2014). Given that sleep quantity decreases with age, it is possible that older populations may be more responsive to acute exercise stimuli due to greater room for change (i.e. not hindered by a ceiling effect) (Youngstedt, 2005). It may also be important to examine sleep patterns following evening HIIE (i.e. within 3 h of bed time) in middle-aged populations compared to HIIE performed in the morning and afternoon (i.e. 4 to 8 h prior to bed time) (Irish et al., 2015) as discouraging early evening HIIE, particularly of short duration, may remove a preferential time-of-day for exercise or eliminate exercise altogether for time-poor individuals (Buman et al., 2014).

Further consideration is needed for metabolic functioning following early evening HIIE and potential changes in subsequent sleep. For instance, should early evening HIIE induce poor sleep outcomes such as shortened total sleep time, and increased sleep onset latency and wake after sleep onset it is likely to be associated with elevations in acylated ghrelin concentration and reduced anorexigenic peptide levels including leptin and PYY (Magee et al., 2009; Omisade et al., 2010; St-Onge et al., 2012b). In isolation, HIIE, has been shown to have a positive effect on acylated ghrelin, leptin and PYY, and further associated with favourable reductions in energy intake for up to 24 h post-exercise (Panissa et al., 2016; Sim et al., 2014; Thivel et al., 2012). However, in these studies, exercise was performed in the morning and due to circadian variations responses may not reflect hormonal changes following exercise performed in the afternoon or early evening. Leptin has been previously examined following a 30 s Wingate anaerobic test performed in the morning (i.e. 1100 h) and evening (2300 h) whereby
authors observed no difference between trials (Bilski et al., 2016). However, ghrelin and PYY have yet to be investigated in relation to exercise time-of-day.

Given the potential interaction between exercise, sleep and appetite, it may be important to investigate the role of exercise on sleep and appetite simultaneously due to the complex pathways which regulate these physiological processes (Copinschi et al., 2014). As such, the aim of this study was to compare the effect of HIIE performed in the morning, afternoon and early evening on sleep, appetite-related hormones and free-living energy intake in inactive, middle-aged men. It was hypothesized that high-intensity afternoon and early evening exercise would increase the proportion of stage N3 sleep compared to baseline and morning exercise; while all exercise trials would induce favourable appetite changes (anorexigenic changes in the circulating hormones and reduced energy intake) due to the implementation of a standardised HIIE protocol.

**Methods**

*Ethical Approval*

Each participant was required to provide informed written consent to the protocols, which were approved by the Charles Sturt University Human Ethics Committee (H16136). This study conformed to the standards set by the Declaration of Helsinki, except for registration in a database.

*Participants*

Eleven overweight, inactive men (mean ± SD; age: 49 ± 5 y; apnoea hypopnea index (AHI): 6 ± 5; BMI: 28 ± 3 kg·m⁻²; VO₂peak: 34 ± 8 ml·kg⁻¹·min⁻¹) completed this study. Inclusion/exclusion criteria included non-smokers, participating in < 150 min of moderate-intensity exercise per week, had no previous or current diagnosis of sleep or metabolic disorders, and no medical conditions or medications that affect
sleep quality or quantity. Volunteers were also excluded if the baseline PSG studies indicated an AHI of ≥ 15. Initially, thirteen men volunteered to participate in the study; however, one participant was excluded due to signs of severe sleep apnoea and one participant withdrew due to an illness unrelated to the study. Sleep was initially assessed by the STOP-BANG questionnaire (Chung et al., 2008), the Epworth Sleepiness Scale (Johns, 1991) and the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989). In accordance with Chung et al. (2008) and Johns (1991), scores of 5 - 8 for the STOP-BANG questionnaire and 16 - 24 for the Epworth Sleepiness Scale were indicative of high risk OSA and excessive sleepiness, respectively. Risk of sleep apnoea was further assessed during two consecutive nights of polysomnography (PSG) measurement. Medical clearance was obtained from a General Practitioner and a Pre-Exercise Medical Health Questionnaire was completed by each participant prior to enrolling in the study to ensure no underlying conditions would be exacerbated by vigorous exercise.

Experimental Overview

Participants attended the laboratory for an initial familiarisation session and baseline assessments of anthropometry and peak oxygen consumption ($\dot{V}O_{2peak}$) and habitual sleep and eating patterns were documented for seven days prior to testing. During this time, two consecutive nights of PSG sleep testing were conducted to exclude sleep apnoea and record normal sleep stages and arousals. Following baseline (BASE), participants completed three experimental trials (3 days duration for each) in a randomised fashion. The experimental trials included 30 min of HIIE (60 s at 100 % $\dot{V}O_{2peak}$: 240 s at 50 % $\dot{V}O_{2peak}$) (Sim et al., 2014) performed 1) in the morning (MORN: 0600 - 0700 h), 2) afternoon (AFT: 1400 - 1600 h), and 3) early evening (EVEN: 1900 - 2000 h). Experimental trials were separated by a minimum of five days recovery. Primary outcome measures included post-exercise sleep quality and quantity, changes in plasma concentrations of appetite-related hormones, ratings of perceived appetite, and post-exercise free-living energy intake.
Familiarisation and Baseline Testing

The familiarisation session involved assessments of height, body mass, and waist and hip girths were completed to calculate body mass index (BMI) and waist-to-hip ratio (WHR), respectively. Further, $V_{\text{O}_2}\text{peak}$ was assessed using a ramp protocol (Barstow et al., 2000) on a cycle ergometer (Lode B.V., Excalibur Sport, Groningen, The Netherlands) to calculate workloads for the experimental trials. The $V_{\text{O}_2}\text{peak}$ test commenced at 50 W for the first 2 min and increased 25 W every minute thereafter with cadence maintained at 70 rpm until volitional exhaustion. During the test, heart rate (HR; F1, Polar, Electro-Oy, Kempele, Finland) was monitored every minute and breath-by-breath pulmonary gas exchange was obtained via a mouthpiece connected to a calibrated metabolic gas oxygen analysis system and custom-developed software (LabVIEW; National Instruments, Austin, TX, USA).

At-home baseline data was obtained for a total of seven days which included seven nights actigraphy recorded via a wrist-worn actigraph (Actiware 2, Philips Respironics, Andover, MA), alongside a diary to verify sleep bed and wake times, and food intake. During this time, participants were instructed to maintain usual bed time, wake time, and diet to provide a representation of typical sleep quantity, sleep behaviour and eating patterns (Bei et al., 2016; Champagne et al., 2013; Rowe et al., 2008). The two nights of PSG sleep measurement were conducted during the seven night baseline period, depending on participant and equipment availability. A level II, take home PSG device was used to exclude sleep disorders and record baseline sleep stages and arousals which were used as a comparative control to the three experimental trials.

Experimental Trials

During each experimental trial, participants did not engage in physical activity and documented all food and drink consumption 24 h prior to exercise. On the day of exercise, participants abstained from
alcohol and caffeine; and fasted overnight for the MORN trial to ensure participant’s sleep on the night prior to exercise was not shortened due to fasting requirements and for 3 h prior to the AFT and EVEN trials. Upon arrival, participants indicated perceived hunger and fullness on validated Visual Analogue Scales (VAS) (Flint et al., 2000) and a capillary blood sample was obtained from the fingertip for the assessment of appetite-related hormones and glucose. Participants then performed the HIIE protocol which consisted of $6 \times 60$ s maximal sprints ($100 \% \text{ VO}_{2\text{peak}}$) interspersed by $240$ s of active recovery ($50 \% \text{ VO}_{2\text{peak}}$) which equated to a total exercise duration of $30$ min (Sim et al., 2014). Exercise was performed on a stationary cycle ergometer (Wattbike Trainer, Wattbike Ltd, Nottingham, UK) and intensity was monitored via power output (PO) every minute. Heart rate (F1, Polar, Electro-Oy, Kempele, Finland) responses were also recorded every minute for calculation and reporting of mean HR across the entire exercise protocol. Participants also reported rating of perceived exertion (RPE; 1-10 scale) (Borg, 1982) every 5 min. Immediately post-exercise, participants were instructed to passively rest for 30 min, after which time a second blood sample was obtained, and perceived appetite was recorded to assess the acute effects of exercise on appetite variables. That night, sleep was recorded using a level II, take home PSG device and scored for sleep stages and arousals. Participants returned to the laboratory the following morning (60 min after waking), for a fasted capillary blood sample and reported perceived appetite to examine appetite variables in relation to the preceding night’s sleep. Actigraphy, and sleep and food records were maintained for three days during each trial, including the day of exercise, one day after exercise, and two days after exercise (refer to Figure 5.1). Data were examined for sleep quantity and energy intake up to 48 h post-exercise. Following exercise, participants were free to choose bed times, wake-up times, and food intake to observe sleep and eating responses to the respective trials.
Figure 5.1 Schematic overview of the study design including baseline data collection followed by exercise time-of-day interventions for the morning (MORN), afternoon (AFT) and evening (EVEN) high-intensity interval exercise trials delivered in a randomised, counter-balanced fashion (n = 11).
**Polysomnography**

Polysomnography was performed using recommended electrode and sensor placements (Berry et al., 2016), connected to the Alice PDx system (Philips Respironics, Pittsburg, USA) and analysed using Sleepware G3 software v3.7.4 (Philips Respironics, Pittsburg, USA). Electrode and sensor placements included: three electroencephalogram (EEG; F3 - A2, C4 - A1, and O1 - A2) electrodes, unilateral electrooculogram (EOG), chin electromyography (EMG), electrocardiography (ECG; lead I), oxygen saturation via pulse oximetry, thoracic and abdominal respiratory effort via belts, and nasal airflow via pressure transducer. The BASE sleep studies were scored to exclude sleep disorders and data were used for the BASE sleep staging and arousal parameters; whereas, only the sleep staging and arousal data were analysed for experimental sleep studies. All sleep studies were scored based on standard guidelines (Berry et al., 2016) by an experienced sleep technologist who was blinded to the experimental trials. Sleep parameters assessed included time in bed, total sleep time (TST), sleep efficiency (SE) \([\text{sleep duration} - \text{wake time}] / \text{sleep duration}] \times 100\), sleep onset latency (SOL; time from lights out to the first epoch of sleep), rapid eye movement (REM) onset latency, wake after sleep onset (WASO; total time awake after sleep onset), percent of time spent in each sleep stage (N1: stage 1; N2: stage 2; N3: stage 3; total NREM: non-rapid eye movement sleep; REM), and arousal index.

**Actigraphy**

Actigraphy was recorded in 1 min epochs (Esliger & Tremblay, 2006) and analysed using Actiware v5.70 software (Philips Respironics, Pittsburgh, USA). Variables obtained included bed time, wake time, time in bed (period between bed time and wake time), TST (time asleep during time in bed), SOL (period between bed time and sleep onset), SE (percent of time in bed spent sleeping), WASO (total time awake after sleep onset), and number of awakenings (Knutson et al., 2007a).
**Appetite Perception and Hormones**

Perceived hunger and fullness were assessed using a VAS comprised of straight lines (100 mm) accompanied by a question anchored with words representing opposing extreme states of hunger and fullness at either end (Flint et al., 2000). A 600 μl sample of blood was collected from a fingertip using a sterile lancet. To assist vasodilation, the hand was submerged in a bowl of warm water for 5 min prior to blood draw. Blood glucose concentration was measured directly from the fingertip using an Accu-Chek Performa (Roche, Manheim, Germany). The remaining blood was immediately aliquoted into pre-chilled EDTA tubes (Becton Dickinson, Sydney, Australia) treated with serine protease inhibitor (25 μl per 600 μl of blood; Pefabloc® SC, Sigma-Aldrich, St. Louis, USA) then immediately centrifuged at 3000 rpm for 10 min. Plasma obtained was stored at -80 °C and later analysed according to manufacturer’s instructions for acylated ghrelin, leptin and PYY\textsubscript{total} using a commercially available assay kit (Cat. No# HEMAG-34K; Milliplex, Millipore Corporation, MA, USA). These hormones were chosen based on previous literature demonstrating their responsiveness to exercise (Balaguera-Cortes et al., 2011; Broom et al., 2009) and association with sleep and appetite (Spiegel et al., 2011). For acylated ghrelin, leptin and PYY\textsubscript{total} the intra- and inter-assay coefficient of variations were < 10 % and < 15 %, respectively.

**Sleep and Energy Intake Records**

Sleep diary entries were used to confirm bedtimes and wake times for actigraphy data. For food records, instructions on the use (including a 1 day example), and the necessity for accurate (i.e. food and drink brands and quantities) and detailed recordings of energy intake immediately after consumption were emphasised. Total energy and macronutrient intake were calculated using commercially available software (Foodworks; Xyris Software, Kenmore Hills, QLD, Australia). Also, absolute (g) and relative data (%) were calculated for carbohydrate, fat and protein intake.
Chapter 5: Study 3

Statistical Analysis

A priori sample size calculations for a repeated measures ANOVA was performed using G*Power (v3.1.9.2) which confirmed that the final sample size of 11 participants was adequate for the input parameters which included the PSG sleep variables as these were the primary study measures. A repeated-measures (trial × time interaction) ANOVA with a Bonferroni correction and Tukey’s post hoc were used to determine significant differences for performance, physiological and perceptual measures, perceived appetite, glucose and appetite-related hormones, total and macronutrient energy intake, PSG and actigraphy variables. PSG data were further separated to analyse the initial 180 min after sleep onset as the first 1 - 2 sleep cycles have been shown to be altered by acute stimuli including evening HIIE (Myllymäki et al., 2012). Analysis was performed using Statistical Package for Social Sciences (SPSS v 20.0, Chicago, USA). Data are reported as mean ± standard deviation (SD) and statistical significance was accepted at p ≤ 0.05.

Results

Exercise Responses

There was no significant difference for mean power output between MORN (355 ± 106 W), AFT (396 ± 126 W) or EVEN (391 ± 139 W) (p = 0.11; Figure 5.2A). As for trial × time interactions, power output was higher at sprint 1 and sprint 2 for AFT compared to MORN (p ≤ 0.05). While for EVEN, power output was greater at sprint 2 compared to MORN (p = 0.01; Figure 5.2A). Mean heart rate was 126 ± 13 bpm for MORN, 132 ± 10 bpm for AFT, and 130 ± 9 bpm for EVEN. Mean heart rate for AFT was higher compared to MORN (p = 0.05). There was no trial × time interaction for RPE; although, a main effect of time for all trials indicated increased RPE from sprint 1 to sprint 6 (p ≤ 0.01; Figure 5.2B).
Figure 5.2 Mean ± SD A. power output; and B. rating of perceived exertion during 30 min high-intensity interval exercise in the morning (MORN), afternoon (AFT) and early evening (EVEN) (n = 11).

d Indicates differences between MORN and AFT (p ≤ 0.05).
e Indicates differences between MORN and EVEN (p ≤ 0.04).
* Indicates a main effect of time for all trials (p ≤ 0.05).
Sleep Questionnaires, Polysomnography and Actigraphy

The results for the STOP-BANG questionnaire, Epworth Sleepiness Scale and PSQI at baseline were 2 ± 1, 7 ± 4 and 5 ± 2, respectively. Whole night and initial 180 min polysomnography data are presented in Table 5.1. There were no significant differences for time in bed, total sleep time, sleep efficiency, sleep onset latency, wake after sleep onset, stage N1 and N2 sleep, or arousal index between BASE, MORN, AFT and EVEN (p > 0.05). However, there was a greater proportion of stage N3 sleep following MORN compared to BASE (p = 0.02). There was a greater proportion of NREM sleep after EVEN compared to BASE for whole night sleep (p = 0.05) and initial 180 min of sleep (p = 0.006). Also, for the initial 180 min of sleep, proportion of REM sleep was lower for EVEN compared to BASE (p = 0.006).

Analysis of actigraphy data (Table 5.2) showed there were no trial × time interactions for all variables (p > 0.05). However, there was a main effect of time for all trials which indicated a lower number of awakenings on the night post-exercise compared to one (p = 0.05) and two days post-exercise (p = 0.04).
Table 5.1 Mean ± SD whole night and initial 180 min polysomnography for baseline (BASE), morning exercise (MORN; n = 10), afternoon exercise (AFT; n = 11), and early evening exercise (EVEN; n = 11) trials.

<table>
<thead>
<tr>
<th></th>
<th>Whole Night</th>
<th>Initial 180 min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BASE</td>
<td>MORN</td>
</tr>
<tr>
<td>Time in bed (min)</td>
<td>484.6 ± 39.8</td>
<td>450.4 ± 43.5</td>
</tr>
<tr>
<td>Total sleep time (min)</td>
<td>405.7 ± 54.4</td>
<td>387.7 ± 55.9</td>
</tr>
<tr>
<td>Sleep efficiency (%)</td>
<td>83.7 ± 6.9</td>
<td>86.0 ± 6.3</td>
</tr>
<tr>
<td>Sleep onset latency (min)</td>
<td>23.1 ± 16.2</td>
<td>19.5 ± 11.7</td>
</tr>
<tr>
<td>Rapid eye movement latency (min)</td>
<td>84.2 ± 21.0</td>
<td>107.9 ± 60.1</td>
</tr>
<tr>
<td>Wake after sleep onset (min)</td>
<td>55.7 ± 32.6</td>
<td>43.1 ± 27.6</td>
</tr>
<tr>
<td>Stage N1 sleep (%)</td>
<td>8.4 ± 4.0</td>
<td>6.8 ± 3.2</td>
</tr>
<tr>
<td>Stage N2 sleep (%)</td>
<td>53.9 ± 5.9</td>
<td>54.2 ± 8.0</td>
</tr>
<tr>
<td>Stage N3 sleep (%)</td>
<td>18.0 ± 7.2</td>
<td>22.9 ± 7.3a</td>
</tr>
<tr>
<td>Non-rapid eye movement (%)</td>
<td>80.3 ± 3.9</td>
<td>83.5 ± 6.7</td>
</tr>
<tr>
<td>Rapid eye movement (%)</td>
<td>19.7 ± 3.9</td>
<td>16.4 ± 6.9</td>
</tr>
<tr>
<td>Arousal index (#·h⁻¹)</td>
<td>12.4 ± 4.2</td>
<td>12.8 ± 3.6</td>
</tr>
</tbody>
</table>

a Indicates differences compared to BASE (p ≤ 0.05).
Table 5.2 Mean ± SD actigraphy sleep data recorded at home for baseline (BASE), day of morning exercise (MORN-0), one day after MORN (MORN+1), two days after MORN (MORN+2), day of afternoon exercise (AFT-0), one day after AFT (AFT+1), two days after AFT (AFT+2), day of early evening exercise (EVEN-0), one day after EVEN (EVEN+1), and two days after EVEN (EVEN+2) (n = 11).

<table>
<thead>
<tr>
<th></th>
<th>BASE</th>
<th>MORN-0</th>
<th>MORN+1</th>
<th>MORN+2</th>
<th>AFT-0</th>
<th>AFT+1</th>
<th>AFT+2</th>
<th>EVEN-0</th>
<th>EVEN+1</th>
<th>EVEN+2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wake time (hh:mm)</td>
<td>6:24 ± 0:45</td>
<td>5:49 ± 0:32</td>
<td>6:21 ± 0:43</td>
<td>6:22 ± 0:51</td>
<td>6:02 ± 0:35</td>
<td>6:22 ± 1:05</td>
<td>6:27 ± 1:13</td>
<td>6:02 ± 0:38</td>
<td>5:59 ± 0:32</td>
<td>5:56 ± 0:34</td>
</tr>
<tr>
<td>Time in bed (hh:mm)</td>
<td>8:02 ± 0:36</td>
<td>7:33 ± 0:34</td>
<td>7:46 ± 0:27</td>
<td>7:59 ± 1:01</td>
<td>7:32 ± 0:37</td>
<td>7:50 ± 0:55</td>
<td>8:01 ± 0:46</td>
<td>7:38 ± 0:43</td>
<td>7:38 ± 0:46</td>
<td>7:22 ± 1:02</td>
</tr>
<tr>
<td>Total sleep time (hh:mm)</td>
<td>6:34 ± 0:32</td>
<td>6:26 ± 0:56</td>
<td>6:20 ± 0:37</td>
<td>6:27 ± 0:48</td>
<td>6:23 ± 0:42</td>
<td>6:39 ± 0:48</td>
<td>6:50 ± 0:42</td>
<td>6:25 ± 0:50</td>
<td>6:36 ± 0:48</td>
<td>6:17 ± 0:57</td>
</tr>
<tr>
<td>Sleep onset latency (min)</td>
<td>14.3 ± 18.9</td>
<td>30.2 ± 30.4</td>
<td>23.5 ± 19.4</td>
<td>31.7 ± 42.7</td>
<td>24.3 ± 21.4</td>
<td>25.1 ± 9.4</td>
<td>24.1 ± 12.7</td>
<td>26.5 ± 23.4</td>
<td>15.5 ± 13.4</td>
<td>12.5 ± 13.6</td>
</tr>
<tr>
<td>Sleep efficiency (%)</td>
<td>82.1 ± 3.6</td>
<td>84.4 ± 9.1</td>
<td>82.3 ± 6.6</td>
<td>82.0 ± 8.9</td>
<td>84.6 ± 8.5</td>
<td>83.1 ± 4.8</td>
<td>84.5 ± 5.8</td>
<td>84.0 ± 7.9</td>
<td>86.3 ± 4.3</td>
<td>85.3 ± 4.4</td>
</tr>
<tr>
<td>Wake after sleep onset (min)</td>
<td>41.1 ± 13.9</td>
<td>29.6 ± 9.1</td>
<td>45.4 ± 18.3</td>
<td>46.3 ± 27.6</td>
<td>32.3 ± 17.6</td>
<td>41.7 ± 18.9</td>
<td>36.1 ± 13.9</td>
<td>35.8 ± 17.6</td>
<td>36.0 ± 8.7</td>
<td>38.2 ± 10.1</td>
</tr>
<tr>
<td>Number of Awakenings (#)</td>
<td>20.4 ± 3.6</td>
<td>17.9 ± 5.3</td>
<td>23.4 ± 6.6*</td>
<td>22.6 ± 8.6*</td>
<td>17.6 ± 4.9</td>
<td>22.3 ± 6.0*</td>
<td>21.8 ± 6.1*</td>
<td>16.9 ± 4.5</td>
<td>21.0 ± 7.4*</td>
<td>22.0 ± 5.9*</td>
</tr>
</tbody>
</table>

* Indicates a main effect of time for all trials (p ≤ 0.05).
Chapter 5: Study 3

Perceived Appetite and Appetite-Related Hormones

There was no trial × time interaction for perceived hunger (p = 0.51) or perceived fullness (p = 0.21; Figure 5.3). The hormone and glucose responses for MORN, AFT and EVEN are shown in Figure 5.4. There was a trial × time interaction for acylated ghrelin, with post hoc analyses revealing significantly higher values pre-exercise for AFT compared to MORN (p = 0.001) and EVEN (p = 0.03), and for EVEN compared to MORN (p = 0.004; Figure 5.4A). Acylated ghrelin remained higher 30 min post-exercise for AFT compared to MORN and EVEN (p = 0.01), while concentrations were higher for EVEN compared to AFT the morning post-exercise (p = 0.01; Figure 5.4A). The percentage change of acylated ghrelin from pre-exercise to 30 min post-exercise was -34 ± 50 % for MORN, for AFT -68 ± 30 % and -74 ± 37 % for EVEN (p = 0.06). Glucose values at 30 min post-exercise were higher for MORN compared to AFT and EVEN (p ≤ 0.02; Figure 5.4D). Also, the percentage change in glucose was 26 ± 25 % for MORN, AFT for 16 ± 21 % and 14 ± 28 % for EVEN from pre to 30 min post-exercise (p = 0.37). There was no trial × time interaction for leptin or PYY<sub>total</sub> (p > 0.05). Although, there was a main effect of time for leptin in which values were higher at pre-exercise and the morning after exercise compared to 30 min post-exercise for all trials (p ≤ 0.01; Figure 5.4B). The percentage change of leptin from pre-exercise to 30 min post-exercise was -35 ± 20 % for MORN, for AFT -34 ± 27 % and -29 ± 16 % for EVEN (p = 0.64). While, the percentage change of PYY<sub>total</sub> from pre-exercise to 30 min post-exercise was 20 ± 61 % for MORN, for AFT 88 ± 157 % and 22 ± 81 % for EVEN (p = 0.17).
Figure 5.3 Mean ± SD A. perceived hunger; and B. perceived fullness on the day of exercise (day 0) at pre-exercise and 30 min post-exercise, and the morning after exercise (day 1 morning) for high-intensity interval exercise in the morning (MORN), afternoon (AFT) and early evening (EVEN) (n = 11).
Figure 5.4 Mean ± SD A. acylated ghrelin; B. leptin; C. peptide tyrosine tyrosine (PYY)\text{total}; and D. glucose on the day of exercise (day 0) at pre-exercise and 30 min post-exercise, and the morning after exercise (day 1 morning) for high-intensity interval exercise in the morning (MORN), afternoon (AFT) and early evening (EVEN) (n = 11).

\text{d} Indicates difference between MORN and AFT (p ≤ 0.02).
\text{e} Indicates difference between MORN and EVEN (p ≤ 0.02).
\text{f} Indicates difference between AFT and EVEN (p ≤ 0.03).
\(*\) Indicates a main effect of time for all trials (p ≤ 0.005).
Free Living Energy Intake

Total energy intake and macronutrient intake is presented in Table 5.3. There were no significant differences between trials for total energy intake ($p = 0.57$), and carbohydrate, fat, protein, sodium, sugar or caffeine intake ($p \geq 0.09$).

Discussion

We investigated the effects of exercise time-of-day on sleep patterns, appetite responses and subsequent free-living energy intake in overweight, inactive men. Our novel findings show that many sleep variables do not differ to HIIE performed at different times of day. Although, the proportion of stage N3 sleep was higher after MORN compared to BASE; and after EVEN there was an increase in NREM sleep and decrease in REM sleep compared to BASE in the initial 180 min of sleep. There was also a favourable decline in acylated ghrelin from pre-exercise to 30 min post-exercise for AFT and EVEN compared to MORN; however, there were only small changes for all trials in leptin and PYY$_{total}$.

Similarly, there were no differences between trials for perceived appetite or energy intake. Additionally, power output of several sprint efforts completed in the AFT and EVEN trials were significantly higher compared to MORN which indicates that participants were able to perform at higher intensities in the latter half of the day. Collectively, these findings indicate that acute early evening HIIE may improve subsequent sleep patterns and is unlikely to alter energy intake compared to exercise performed at other times of day or to no exercise. Although, the greater efforts during maximal sprints in the afternoon and early evening may stimulate larger reductions of orexigenic signals compared to morning HIIE which would likely be of more benefit to appetite control long-term.
Table 5.3 Mean ± SD total energy and macronutrient breakdown for baseline (BASE), day of morning exercise (MORN-0), one day after MORN (MORN-1), two days after MORN (MORN-2), day of afternoon exercise (AFT-0), one day after AFT (AFT+1), two days after AFT (AFT+2), day of early evening (EVEN-0), one day after EVEN (EVEN+1), two days after EVEN (EVEN+2) (n = 11).

<table>
<thead>
<tr>
<th></th>
<th>BASE</th>
<th>MORN-0</th>
<th>MORN+1</th>
<th>MORN+2</th>
<th>AFT-0</th>
<th>AFT+1</th>
<th>AFT+2</th>
<th>EVEN-0</th>
<th>EVEN+1</th>
<th>EVEN+2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Energy Intake (kJ)</td>
<td>8501 ± 3248</td>
<td>8162 ± 4274</td>
<td>8167 ± 4166</td>
<td>7583 ± 2928</td>
<td>7839 ± 1283</td>
<td>7215 ± 3266</td>
<td>7813 ± 3544</td>
<td>6954 ± 1337</td>
<td>6856 ± 3294</td>
<td>6238 ± 1641</td>
</tr>
<tr>
<td>Carbohydrates (g)</td>
<td>204 ± 84</td>
<td>160 ± 14</td>
<td>161 ± 38</td>
<td>175 ± 87</td>
<td>220 ± 88</td>
<td>179 ± 72</td>
<td>169 ± 44</td>
<td>210 ± 113</td>
<td>179 ± 77</td>
<td>138 ± 36</td>
</tr>
<tr>
<td>(%)</td>
<td>41 ± 7</td>
<td>41 ± 10</td>
<td>37 ± 5</td>
<td>39 ± 10</td>
<td>43 ± 10</td>
<td>40 ± 1</td>
<td>42 ± 9</td>
<td>44 ± 14</td>
<td>46 ± 10</td>
<td>36 ± 6</td>
</tr>
<tr>
<td>Fats (g)</td>
<td>78 ± 37</td>
<td>73 ± 42</td>
<td>60 ± 23</td>
<td>68 ± 29</td>
<td>83 ± 28</td>
<td>66 ± 43</td>
<td>61 ± 34</td>
<td>70 ± 22</td>
<td>51 ± 21</td>
<td>67 ± 32</td>
</tr>
<tr>
<td>(%)</td>
<td>34 ± 6</td>
<td>33 ± 8</td>
<td>33 ± 7</td>
<td>34 ± 7</td>
<td>37 ± 6</td>
<td>32 ± 10</td>
<td>30 ± 8</td>
<td>36 ± 11</td>
<td>35 ± 8</td>
<td>35 ± 6</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>97 ± 37</td>
<td>92 ± 51</td>
<td>96 ± 41</td>
<td>86 ± 27</td>
<td>93 ± 37</td>
<td>79 ± 38</td>
<td>80 ± 45</td>
<td>93 ± 30</td>
<td>69 ± 30</td>
<td>84 ± 41</td>
</tr>
<tr>
<td>(%)</td>
<td>19 ± 3</td>
<td>19 ± 4</td>
<td>20 ± 4</td>
<td>20 ± 5</td>
<td>18 ± 5</td>
<td>18 ± 4</td>
<td>16 ± 4</td>
<td>19 ± 3</td>
<td>17 ± 4</td>
<td>19 ± 4</td>
</tr>
<tr>
<td>Sodium (mg)</td>
<td>2078 ± 349</td>
<td>2511 ± 1400</td>
<td>2384 ± 1338</td>
<td>2302 ± 1136</td>
<td>2658 ± 713</td>
<td>1985 ± 1372</td>
<td>1655 ± 665</td>
<td>2890 ± 1210</td>
<td>1956 ± 1089</td>
<td>2112 ± 1053</td>
</tr>
<tr>
<td>Sugar (g)</td>
<td>81 ± 41</td>
<td>59 ± 17</td>
<td>72 ± 49</td>
<td>62 ± 18</td>
<td>85 ± 46</td>
<td>66 ± 46</td>
<td>73 ± 49</td>
<td>93 ± 64</td>
<td>81 ± 49</td>
<td>54 ± 17</td>
</tr>
<tr>
<td>Caffeine (mg)</td>
<td>146 ± 76</td>
<td>83 ± 69</td>
<td>113 ± 70</td>
<td>129 ± 104</td>
<td>100 ± 86</td>
<td>100 ± 78</td>
<td>125 ± 78</td>
<td>137 ± 107</td>
<td>155 ± 90</td>
<td>164 ± 89</td>
</tr>
</tbody>
</table>
Findings from the present study are consistent with experimental evidence suggesting that vigorous exercise performed close to bedtime does not disrupt sleep (Flausino et al., 2012; Hayashi et al., 2014; Myllymäki et al., 2011; O’Connor et al., 1998; Robey et al., 2013; Youngstedt et al., 1999). Following the EVEN trial, PSG data indicated an increase in NREM sleep and decrease in REM sleep predominantly within the initial 180 min of sleep which have also been previously reported by Netzer et al. (2001) and Robey et al. (2013). Netzer et al. (2001) further presented a correlation between an extension of REM onset latency and reduction of REM sleep percentage in the first half of sleep with an increase in norepinephrine following intense exercise. Although the mechanisms are not fully understood, it is known that noradrenergic cells are tonically active during all sleep stages except for REM sleep (Poe et al., 2010). Given that HIIE, compared to moderate-intensity exercise, is associated with a post-exercise 14.5-fold increase in norepinephrine release (Boutcher, 2010), it is plausible that the presence of such high levels close to bed time are linked to delayed REM sleep. Norepinephrine may further enhance and prolong long-term potentiation (i.e. persistent strengthening of synapses based on recent patterns of activity) which occurs during NREM sleep stages and facilitates the events to convert early long-term potentiation to lasting long-term potentiation (Poe et al., 2010). Nonetheless, opposing findings for early evening vigorous exercise have been presented by Souissi et al. (2012) whereby total sleep time and sleep efficiency were lower, and sleep onset latency and awakenings increased compared to afternoon vigorous exercise. As such, further research is needed to examine the potential influence of covariates including age, gender and training status, that may affect sleep responses to early-to-late evening HIIE.

Limited differences were observed in appetite responses; although, for the hormone changes, it did appear that AFT and EVEN induced greater changes in acylated ghrelin, while MORN altered glucose only. Interestingly, there was large variation in pre-exercise acylated ghrelin concentrations which are likely attributed to the natural circadian rhythm of this hormone; which is typically lowest in the
morning before progressively increasing until mid-afternoon (Birketvedt et al., 2012; Copinschi et al., 2014). As such, relative changes following exercise compared to pre-exercise values for the respective trials may provide a clearer understanding of time-of-day effects on circulating ghrelin. In this study, the magnitude of change for acylated ghrelin was larger following AFT and EVEN trials compared to changes after MORN, but these differences were not significant. Nonetheless, it is possible that the sprint power output differences between the AFT and EVEN trials compared to the MORN trial induced the observed ghrelin changes from pre-exercise to 30 min post-exercise. In support, Sim et al. (2014) observed a significantly greater reduction in ghrelin concentration for a very high-intensity exercise protocol compared to HIIE, moderate-intensity continuous exercise and a non-exercise control trial. Further, lower ghrelin levels continued for the very high-intensity protocol for up to 90 min post-exercise (Sim et al., 2014). Despite implementing the same HIIE protocol for all trials in the current study, sprint power output, particularly for the first 2 sprints, was higher for AFT and EVEN compared to the MORN trial. These data are largely supported by previous findings which report that maximal short-duration performance output nadirs in the morning and peaks in the afternoon in general and athletic populations (Atkinson, Coldwells, Reilly, & Waterhouse, 1993; Souissi et al., 2012; Souissi et al., 2007; Souissi et al., 2002; Souissi et al., 2004). Therefore, it may be more beneficial to engage in HIIE in the afternoon and early evening as performance output is likely to be greater leading to larger reductions in orexigenic signals.

Despite the reduction in acylated ghrelin levels post-HIIE in the AFT and EVEN trials, there were no associated reduction in perceived appetite or energy intake in this study. Much of the research investigating energy intake following exercise has been conducted during morning hours. Bilski et al. (2016) previously measured leptin following morning and evening high-intensity exercise, finding no difference between trials. However, unlike the current study, authors did observe a reduction in perceived hunger and post-exercise energy intake following both morning and evening high-intensity
exercise (Bilski et al., 2016). Differences between studies may be due to the provision of an *ad-libitum* meal to examine post-exercise energy intake compared to the self-reported diaries used in the present study which may not be sensitive enough to detect significant changes in energy intake. Furthermore, Bilski et al. (2016) only examined energy intake immediately post-exercise while the present study investigated potential long-lasting exercise effects on energy intake (i.e. up to 48 h post-exercise).

The novel aspect of the current study is the examination of sleep and appetite concurrently following this distinct times-of-day. Even so, there are several limitations which need to be addressed and may assist the direction of future research. The difference in time of fasting for the MORN trial (i.e. 10 h overnight) compared to the AFT and EVEN trials (i.e. 3 h) are likely to effect diurnal variations of the appetite-related hormones and glucose concentration. However, the overnight fast was chosen for the MORN trial to avoid forced sleep restriction which may also result in altered diurnal responses (Spiegel et al., 2004b). There was a minor shift in dinner time for the EVEN trial (20:29 ± 0:27 h) of approximately 1 h compared to BASE (19:21 ± 0:27 h) which may have also been a contributor to the observed sleep changes considering that previous research has indicated that regular ‘late dinner times’ at 21:00 h or later are associated with shorter sleep duration (e.g. ≤ 5 h sleep per night) (Hsieh et al., 2011). Also, there were limited time points for the analysis of acylated ghrelin, leptin, PYY_{total} and glucose; however, the three designated time points are in alignment with capturing acute and prolonged responses across all hormones. Eating and sleep behaviour may have influenced energy intake rather than changes in feeding mechanisms following HIIE performed at different times of the day. As such, future research may benefit from assessing prolonged energy intake in a controlled laboratory setting and collecting more frequent blood samples to identify diurnal changes of appetite-related hormones and glucose after HIIE performed in the morning, afternoon and early evening.
In summary, this study does not support the recommendation of avoidance of early evening HIIE due to its effect on sleep. Rather this study shows HIIE can be safely performed in the early evening without subsequent detriment to sleep duration or arousal index. Also, HIIE performed in the afternoon and early evening are likely to be associated with greater performance output; therefore, greater reductions in orexigenic signals. As such, collectively these observations support the early evening as a viable time-of-day for individuals to engage in HIIE should this be a preferential time-of-day.
Chapter Six: General Discussion
Chapter 6: General Discussion

6.1 Overview of the Thesis
This thesis investigated (1) the relationships between sleep, eating and exercise in inactive middle-aged men, (2) the effects of prolonged (three consecutive nights) sleepcurtailment and extension on appetite-related hormones, perceived appetite and cravings, and mood states in inactive men, (3) the effects of exercise on appetite-related hormones, perceived appetite and cravings, and mood states following prolonged sleep curtailment and extension in inactive men, and (4) the acute effects of exercise intensity and exercise time-of-day on subsequent sleep, appetite-related hormones, and perceived appetite in inactive men. In relation to aim (1), Chapters Three, Four and Five concurrently explored the interactions between sleep, appetite and exercise under enforced sleep manipulation and exercise interventions. Specifically, prolonged sleep manipulation trials (RES, FRAG, EXT) were implemented (Chapter Three) to address thesis aim (2) short-duration, vigorous exercise was utilised to assess potential therapeutic effects on appetite and mood following sleep manipulation to address aim (4). Lastly, in addressing thesis aim (3), Chapter Four investigated the differences between exercise intensities and Chapter Five investigated the differences between exercise time-of-day on sleep and appetite to determine the more effective intensity and time-of-day for exercise engagement for inactive, middle-aged populations. Collectively, the three studies conducted for this thesis demonstrate both physiological and behavioural interactions between sleep, appetite and exercise; however, mood also influences the multi-directional relationship between the key behaviours.

6.2 Summary of Major Findings

Chapter Three - Sleep manipulation on appetite and mood

Thesis aim (1) and (2) was addressed in Chapter Three which investigated the effects of sleep curtailment and extension on appetite-related hormones, perceived appetite and mood among middle-aged, inactive men compared to normal sleep. It appeared that RES had a greater effect on appetite variables, including
the stimulation of orexigenic signals, leading to increased perceived appetite and cravings for sweet foods. Whereas, FRAG tended to induce have a greater negative effect on mood and perceptual outcomes, such as increased fatigue and stress, and reduced sleep quality. EXT did not induce additional benefits compared to CONT but rather resulted in increased feelings of stress; thus, improving sleep continuity may be more important among middle-aged adults opposed to increasing sleep duration. In addition, appetite and mood responses (reduced food cravings and stress) following the 20 min vigorous exercise session were suggestive of a mitigated effect in which detrimental sleep effects were dampened by exercise.

Chapter Four - Effects of exercise intensity

In addressing thesis aim (1) and part one of thesis aim (3), Chapter Four examined the effect of HIIE compared to traditional MICE on sleep characteristics, appetite responses and subsequent free-living energy intake in overweight, inactive men. Results indicated that HIIE induced greater sleep and appetite changes compared to MICE. Specifically, following HIIE there was an increased proportion of stage N3 sleep and total NREM sleep, and reduced REM sleep and arousals during REM sleep compared to BASE. For appetite, circulating acylated ghrelin was lower and glucose concentrations were higher transiently after HIIE compared to MICE. Together, these results suggest that higher exercise intensities are required to induce physiological changes in sleep and appetite; however, subsequent HIIE bouts may be required to compound these effects and alter perceptual/behavioural appetite.
Chapter 5 - Effects of exercise time-of-day

Chapter Five addressed thesis aim (1) and part two of thesis aim (3) as it investigated the effects of HIIE time-of-day on sleep characteristics, appetite responses and subsequent free-living energy intake in overweight, inactive men. Sleep results demonstrated greater stage N3 sleep after MORN compared to BASE; whereas, an increase in NREM and decrease in REM sleep was shown in the initial 180 min of sleep after EVEN. The appetite responses indicated a greater reduction in acylated ghrelin after AFT and EVEN compared to MORN, perhaps due to the greater sprint power output observed during exercise. However, the decline in this orexigenic signal was not associated with reductions in perceived appetite or free-living energy intake. Nevertheless, this study shows that HIIE can be safely performed at any time of day, including early evening, without subsequent detriment to sleep duration or arousal index. Also, HIIE performed in the afternoon or evening are likely to be associated with greater performance output; therefore, greater reductions in orexigenic signals which may result in decreased perceived appetite and energy intake long-term. As such, these observations support the evening as a viable time-of-day for individuals to engage in HIIE, should this be a preferential time-of-day.
Figure 6.1 Thesis schematic of the three key domains explored with the introduction of mood which was a reoccurring factor throughout the series of studies: Chapter Three (3), Chapter Four (4) and Chapter Five (5).
6.3 The therapeutic effects of vigorous exercise on sleep, eating behaviour and appetite regulation, and mood states

*Physiological and perceptual sleep, appetite and mood responses to acute exercise*

This thesis revealed that higher intensity exercise is required to induce subsequent physiological changes in sleep and appetite in inactive, middle-aged men; however, perceptual and behavioural factors of these key domains may not be sensitive to such transient changes. Key sleep findings from Chapter Four not only showed an increase in stage N3 sleep following HIIE; but also, an increase in NREM and reduced REM sleep in the initial 180 min of sleep, suggesting that HIIE may redistribute sleep stages reflecting ideal sleep patterns (Copinschi et al., 2014; Rama et al., 2005; Sharma & Kavuru, 2010). In addition, Chapter Five revealed that stage N3 sleep was increased following HIIE performed in the morning only; whereas, increased NREM and decreased REM sleep in the initial 180 min of sleep was observed for the EVEN trial. The sleep changes observed during the EVEN trial have been previously observed (Netzer et al., 2001; Robey et al., 2013); and, although not yet fully elucidated, there are several mechanisms which may contribute to these observed responses.

A possible explanation for the improved sleep following HIIE in Chapter Four is the increased physiological stress that is associated with HIE compared to MICE (Burgomaster et al., 2005; Crisp et al., 2012; Helgerud et al., 2007; Wisløff et al., 2007). Compared to MICE, HIE/HIIE is associated with a greater magnitude of change in heart rate, release of metabolic hormones including growth hormone, lactate concentrations, and depletion of adenosine triphosphate, creatine phosphate and glycogen stores (Boutcher, 2010; Tomlin & Wenger, 2001; Trapp et al., 2007; Weinstein et al., 1998). Given the vigorous nature of the HIIE protocol, it is possible that participants experienced greater glycogen depletion and metabolite accumulation resulting in the need for a longer recovery duration (Boutcher, 2010; Laforgia et al., 2006) despite only cycling for a total of 6 min compared to 20 min in the MICE trial. Further, recovery time for the participants of Chapter Four and Five may have been extended further due to their untrained state which has been associated with slower rates of recovery compared
to trained counterparts (Børsheim & Bahr, 2003; Gore & Withers, 1990). Since increased stage N3 sleep was observed following HIIE, but not MICE, it is plausible that higher intensity exercise increases the need for peripheral restoration, and vital growth and repair in subsequent nocturnal sleep (Tasali et al., 2008). Nonetheless, this potential mechanism that stimulates stage N3 sleep following HIIE is likely not a primary contributor because, as shown in Chapter Five, only morning HIIE was associated with increased stage N3 sleep.

The sleep changes observed in the initial 180 min of sleep following HIIE in Chapter Four and EVEN in Chapter Five support the notion of a potential role of the autonomic nervous system (ANS) in the regulation of REM sleep (Netzer et al., 2001). Netzer et al. (2001) reported a correlation between delayed REM onset latency and reduced proportion of REM sleep in the first half of sleep with an increase in norepinephrine following intense exercise. While further investigation for the change in REM sleep distribution is warranted, it is known that noradrenergic cells are tonically active during all sleep stages except for REM sleep (Poe et al., 2010). Also, HIIE is associated with a 14.5-fold increase in post-exercise norepinephrine compared to MICE (Boutcher, 2010). Therefore, it is possible that the presence of higher levels of HIIE-induced norepinephrine close to bedtime delayed REM sleep onset. Furthermore, norepinephrine has been shown to enhance and prolong long-term potentiation (persistent strengthening of synapses based on recent patterns of activity) which occurs during NREM sleep stages (Poe et al., 2010). As such, it is possible that HIIE facilitates events for early long-term potentiation to lasting long-term potentiation, thus supporting neural plasticity, learning and memory (Bliss & Cooke, 2006). Moreover, it appears that HIIE performed at any time of day may facilitate these neurological events given that sleep improvements were observed following the MORN and EVEN trials of Chapter Five.
The acute exercise protocols utilised in the current thesis were shown to also induce transient appetite-related changes; however, the association between appetite-related hormones and perceptual measures of appetite did not align as expected. In Chapter Four, significant reductions in post-exercise acylated ghrelin were observed for HIIE compared to MICE. Chapter Five further indicated that these reductions may be more prominent when HIIE was performed in the afternoon or evening rather than the morning. However, in both Chapters Four and Five there was no associated change in perceived hunger or energy intake, regardless of exercise intensity or time-of-day. These findings are contrary to previous literature which has observed a reduction in perceived appetite and energy intake for up to 24 h after HIIE (Sim et al., 2014; Thivel et al., 2012). Nevertheless, food records in Chapter Four did indicate lower energy intake (albeit not significant) for the remainder of the exercise day following HIIE compared to MICE. This supports the notion that higher exercise intensities may induce greater reductions in energy intake compared to MICE; however, perhaps long-term HIIE training is required to compound anorexigenic effects and improve appetite regulation. For instance, several training studies have reported modifications in perceived appetite, eating behaviour and energy intake from pre- to post-training (Alkahtani et al., 2014; King et al., 2011; Sim, Wallman, Fairchild, & Guelfi, 2015). Specifically, a three month exercise program designed to expend 500 kcal·day\(^{-1}\), with no dietary intervention, demonstrated that overweight and obese individuals who experienced decreased disinhibition and increased restraint also experienced greater weight loss compared to participants who did not report altered eating behaviour (Bryant, 2009; King et al., 2008; King et al., 2009). Alkahtani et al. (2014) also observed exercise-induced reductions in hunger, desire to eat, liking for high-fat non-sweet food, and fat intake (16%) following four weeks of HIIE compared to MICE. Further, while Sim et al. (2015) did not observe changes in perceived appetite or appetite-related blood variables following 12 weeks of HIIE, the authors did report a clinically meaningful decrease in energy intake after a high-energy preload compared to a low-energy preload.
Evidence in Chapters Three and Four support the concept that exercise, particularly of vigorous-high intensities, inhibit neurological food reward pathways and/or suppress the neural responses to high-calorie foods (Cornier et al., 2012; Crabtree, Chambers, Hardwick, & Blannin, 2014; Evero et al., 2012).

In Chapter Three, cravings for sweet foods was increased following RES compared to CONT; however, there was a trend for decreased sweet food cravings after exercise, suggesting that the 20 min vigorous exercise protocol mitigated perceived cravings. Moreover, in Chapter Four, in the two days following both HIIE and MICE sugar intake was lower compared to BASE, which may reflect day-to-day dietary variations when considered in isolation (Champagne et al., 2013). However, when considered collectively Chapters Three and Four suggest that not only does exercise suppress individuals’ receptiveness to sweet foods but also downregulates the consumption of sweet foods for up to 48 h post-exercise. Crabtree et al. (2014) observed suppressed activation in the orbitofrontal cortex (OFC), which mediates feeding behaviour, as well as significantly increased PYY and decreased acylated ghrelin which supports the idea for exercise-induced changes in the neuroendocrine pathways. Whereas, the disassociation between appetite-related hormones and perceived appetite in Chapters Three (changes in perceived appetite despite minimal hormone changes), Four and Five (no changes in perceived appetite despite favourable hormone changes) suggest that exercise may induce beneficial changes in a variety of ways not just through neuroendocrine pathways.

A possible explanation for the reduced sweet cravings from post-sleep manipulation to post-exercise in the RES trial of Chapter Three may in part be due to the slight alleviation of negative mood states after exercise. As such, it appeared that the 20 min cycling bout slightly improved some of the mood variables (e.g. reduced fatigue, increased vigour), thus cumulatively reducing TMD. Hansen et al. (2001) investigated exercise duration and mood state, finding that peak improvements of vigour with reductions in fatigue, confusion and TMD were reached within 20 min of MICE. In a recent review, Basso and Suzuki (2017) presented evidence which demonstrates that exercise stimulates the increase
of neurochemicals (e.g. lactate and cortisol), neurotrophins (e.g. brain derived neurotrophic factor and insulin-like growth factor 1), neurotransmitters (e.g. dopamine and norepinephrine), and neuromodulators (e.g. endogenous opioids and endocannabinoids) that collectively contribute to the improvement of mood. Given that Chapter Three observed reductions in mood, increases in perceived appetite and food cravings prior to exercise during the sleep loss trials, it is plausible that the exercise-induced enhancements of mood and suppression of appetite were blunted. Considering many are likely to be sleep deprived (Hirshkowitz et al., 2015) and that heightened negative mood states are associated with greater sugar consumption (Moubarac et al., 2013); it is plausible that exercise may alleviate negative mood states associated with sleep loss, and aid in the improvement of subsequent sleep bouts (Asmundson et al., 2013). The beneficial changes in sleep and mood would likely lead to reductions in the compensatory rise in sugary foods that tend occur when sleep deprived or experiencing increased feelings of fatigue and stress (Bosy-Westphael et al., 2008; Moubarac et al., 2013; Nedeltcheva et al., 2009; St-Onge et al., 2011; Tataranni et al., 1996).

As shown in Chapter Five, the lack of change in perceived appetite, particularly for the AFT and EVEN trials, were unexpected considering the significant decline of acylated ghrelin from pre to post-exercise. Nonetheless, previous findings have suggested that during the afternoon and evening, individuals may be more susceptible to overeating particularly when paired with perceived stress (Carnell et al., 2017). Therefore, despite no changes in perceived appetite or energy intake in Chapter Five it is plausible that the mere engagement of exercise at these times may reduce the risk of overconsumption and reduce total daily energy intake given that exercise participation reduces the time available to consume food.
6.4 Appetite-related changes associated with poor sleep and mood states

The findings from Chapter Three support current literature which report a high prevalence of regular insufficient sleep and associated increases in negative mood states among middle-aged cohorts (Adams et al., 2017; Chaput, 2014; Kahn et al., 2013; McEwen, 2008), and consequential impairments to dietary control (Adam & Epel, 2007; Gibson, 2006; Magee et al., 2009; Moubarac et al., 2013; Spiegel et al., 2004a; Spiegel et al., 2004b). However, the novel aspect of this thesis is that Chapter Three demonstrated increased stress associated with sleep extension compared to all other sleep conditions and supported the notion that prolonged sleep curtailment is detrimental to both appetite and mood outcomes. As such, while inactive, middle-aged men require holistic management of sleep, diet, exercise and mood; the most effective strategies would likely be those that focus on improving sleep continuity rather than increasing sleep duration. These improvements in sleep would likely be further associated with improved sensitivity to appetite signals, management of energy intake and improve mood and emotional stability.

Effects of sleep on appetite regulation

There are complex interactions between sensory, physiological, psychological and social demands which influence circadian rhythms of regulating peptides, neuroendocrine pathways, and brain activation result in changes to sleep, eating and mood behaviours (Adam & Epel, 2007; Copinschi et al., 2014; Macht, 2008; Moubarac et al., 2013; Spiegel et al., 2004b). While it is difficult to determine the initial stimulator(s) for detrimental effects on these behaviours, it appears that appetite regulation and eating behaviour are particularly sensitive to changes in sleep (e.g. RES) and mood/emotional cues (Adam & Epel, 2007; Copinschi et al., 2014; Gibson, 2006; Macht, 2008; Moubarac et al., 2013; Spiegel et al., 2004a; Spiegel et al., 2004b). Chapter Three supports the notion that several mechanisms, including homeostatic stimuli (e.g. changes in key appetite-related hormones) and hedonic stimuli...
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(e.g. timing and opportunity for eating, and negative changes in mood states) may upregulate the drive for food consumption during sleep curtailment (Figure 6.2) (Chaput, 2014).

Chapter Three reported changes in homeostatic stimuli, demonstrating that restricted sleep increased orexigenic and decreased anorexigenic signals, which is indicative of increased drive to eat. This evidence supports previous literature which has predominantly focused on the responses of acylated ghrelin and leptin to RES (Brondel et al., 2010; Spiegel et al., 2004a; Spiegel et al., 2004b) while also supporting the notion that alterations in other appetite-related hormones (e.g. PYY_total) contribute to the increased drive for food consumption (Magee et al., 2009). As such, it is plausible that the peptides measured in Chapter Three are some of the initial respondents to sleep loss, signalling the brain to stimulate feeding to reduce impending feelings of fatigue, offset increased energy expenditure and better cope with extended wake periods (Chaput, 2014; Copinschi et al., 2014; García-García et al., 2014).

In reference to acylated ghrelin, the primary function of this hormone during wakefulness is to stimulate appetite by concurrently activating orexigenic neuropeptides (NPY and AgRP) and deactivating anorexigenic neuropeptides, including POMC, CART and α-MSH (Arora, 2006; Kojima et al., 1999). Alternatively, nocturnal rises in acylated ghrelin contributes to NREM onset, reduced REM sleep and the release of growth hormone (GH) (Dzaja et al., 2004; García-García et al., 2014; Nass et al., 2008; Weikel et al., 2003). During sleep loss, the release of GH is inhibited despite elevated ghrelin concentrations, which leads to increased circulating glucose, as GH is unable to effectively exert its metabolic effects on fat and muscle tissues (García-García et al., 2014; Van Cauter, Spiegel, Tasali, & Leproult, 2008). When this process is prolonged, insulin resistance and glucose intolerance can ensue which increases the risk of developing TIIDM (Knutson & Van Cauter, 2008). Moreover, elevated acylated ghrelin induced by sleep deprivation is associated with increased perceived appetite and
energy intake (Brondel et al., 2010; Nedeltcheva et al., 2009; Spiegel et al., 2004b), indicating that extended wakefulness stimulates continuing activation of orexigenic neuroendocrine pathways when they would otherwise be predominantly dormant.

![Diagram](image.png)

**Figure 6.2** Potential mechanisms by which insufficient sleep may facilitate the ingestion of calories. Image from Chaput (2014).

Leptin opposes the function of acylated ghrelin during wakefulness by inhibiting orexigenic neuropeptides (e.g. NPY and AgRP) and stimulating anorexigenic neuropeptides (POMC and CART) to suppress feelings of hunger and energy intake (Morselli et al., 2012). However, nocturnal increases in leptin have a similar function as acylated ghrelin, as shown by the promotion of NREM sleep and reduction in REM sleep (García-García et al., 2014; Willie et al., 2001). In response to sleep loss, circulating leptin has previously been shown to decrease (Mullington et al., 2003; Spiegel et al., 2004a; Spiegel et al., 2004b); however, this finding was not evident in the results for Chapter Three. Despite,
lower leptin following the RES trial compared to all other trials, this difference did not reach statistical significance ($p = 0.12 - 0.38$). Conversely, Spiegel et al. (2004a) reported a 19% reduction in leptin following six nights of 4 h RES compared to seven nights of 12 h EXT, despite standardising caloric intake and physical activity, and observing no change in BMI. It is plausible that the discrepancies between studies are due to differences in the duration of sleep manipulation (three nights compared to six nights) or that the single blood sample taken after sleep manipulation in Chapter Three was not sensitive enough to detect between-trial differences. Regardless, it has been postulated that decreased leptin during sleep loss may occur due to two primary mechanisms (Havel, 2007; Mullington et al., 2003; Spiegel et al., 2004a). It has been shown that insulin stimulates the release of leptin by increasing glucose uptake and metabolism (Havel, 2007); however, during sleep loss, evidence suggests that the signal amplitude of insulin decreases, likely leading to acute reductions in leptin concentration (Mullington et al., 2003). In addition, several studies have shown that extended wakefulness is associated with sustained sympathetic nervous system (SNS) activity (Burgess, Trinder, Kim, & Luke, 1997; Somers, Dyken, Clary, & Abboud, 1995), which is a key regulator of leptin production in adipose tissue (Rayner & Trayhurn, 2001; Spiegel et al., 2004a). Specifically, increased SNS activity inhibits leptin gene expression and leptin production; whereas, the inhibition of SNS activity allows for the increase in circulating leptin and leptin gene expression (Rayner & Trayhurn, 2001).

Although leptin was not statistically lower following RES in Chapter Three, $PYY_{total}$ was lower compared to all other trials. The response of PYY to sleep manipulation has not been extensively examined; although, mixed findings have been presented following RES protocols in three known studies (Magee et al., 2009; Markwald et al., 2013; St-Onge et al., 2012b). $PYY_{total}$ results from Chapter Three closely align with findings presented by Magee et al. (2009) who reported that PYY was much lower after RES (78 pg·mL$^{-1}$, two nights of 5 h sleep) compared to EXT (90 pg·mL$^{-1}$, 1 night of 8 - 10 h sleep) among ten
men (20 y). Conversely, St-Onge et al. (2012b) and Markwald et al. (2013) observed no significant differences in PYY following CONT (3 - 5 nights of 8 - 9 h sleep) and RES (3 - 5 nights of 4 - 5 h sleep). The discrepancies between these results may, in part, be due to sex-related differences to sleep-induced peptide responses. Further, when observing PYY data for the men and women recruited by St-Onge et al. (2012b) and Markwald et al. (2013), a non-significant decrease in PYY is noted following RES in men (4 pg·ml⁻¹ and ≈ 3 pg·ml⁻¹); whereas, there was a slight increase in PYY for women (7 pg·ml⁻¹ and ≈ 10 pg·ml⁻¹). Given the limited data and inconsistencies between study findings, the potential mechanisms underlying PYY responses to sleep loss remain to be identified. Nevertheless, under normal sleep conditions, PYY is known to act on the hypothalamus, via vagal pathways afferent to the brainstem, to reduce food intake (Magee, Huang, Iverson, & Caputi, 2010; Valassi, Scacchi, & Cavagnini, 2008). As such, it is possible that sleep loss not only interferes with leptin-dependent pathways but also PYY-dependent pathways in conjunction to stimulating ghrelin-dependent pathways; thus, creating an environment whereby orexigenic signals are unopposed.

Increases in perceived appetite and energy intake have been previously observed following sleep deprivation trials despite no significant changes in appetite-related hormones (Bosy-Westphal et al., 2008; Markwald et al., 2013; Nedeltcheva et al., 2009; Omisade et al., 2010; Pejovic et al., 2010; Simpson et al., 2010), which has led some to speculate that there are other factors which contribute to the increased drive to consume food (Chaput, 2014). Primary contributors appear to be hedonic factors, such as increased negative mood states and activation of brain regions associated with food reward (Chaput, 2014; Moubarac et al., 2013; St-Onge et al., 2012a; St-Onge et al., 2014). Moubarac et al. (2013) demonstrated a clear link between the effects of insufficient sleep and psychological distress, as defined by increased negative mood states and stress, on eating behaviour. The authors reported that participants who experienced high psychological distress consumed 45 - 68 % more sugar per day compared to those who reported low-moderate psychological distress; while high
daytime sleepiness was associated with 23 - 54 % higher sugar intake compared to low-moderate daytime sleepiness (Moubarac et al., 2013). Chapter Three further demonstrates the role of hedonic stimuli on perceived appetite and eating behaviour due to the observed association between poor sleep quality, negative mood states, disinhibition and hunger; and the detrimental appetite and mood responses induced by RES and FRAG. Further research has also revealed that insufficient sleep in combination with higher negative mood states are associated with increased frequency of snacking, total energy intake and higher fat consumption (Bosy-Westphal et al., 2008; Nedeltcheva et al., 2009; St-Onge et al., 2011; Tataranni et al., 1996). Several mechanisms, including upregulated peptides and brain stimulation, have been identified as likely contributors to the hedonic stimuli which upregulates appetite during sleep loss and increased negative mood states, simultaneously and in isolation (Adam & Epel, 2007; Finan et al., 2015; Gujar et al., 2011; Lentz et al., 1999; St-Onge et al., 2012a; St-Onge & Shechter, 2013; Yoo et al., 2007).

In isolation, enforced RES (6 nights of 4 h sleep) relative to habitual sleep has been shown to increase the stimulation of the orbitofrontal Cortex (OFC) and insula, which process the rewarding quality of foods when individuals are presented with food stimuli (St-Onge et al., 2012a; St-Onge et al., 2014). St-Onge et al. (2014) conducted an analysis which revealed that a greater number of neurons are activated in these reward centres when sleep deprived individuals are presented with visuals of ‘unhealthy’ food compared to ‘healthy’ food. Given the role of the insula in energy homeostasis, pleasure-seeking behaviours, response to external stimuli, salience and monitoring of arousal states; the increased activity in this region during RES supports the presence of a regulatory mechanism which encompasses subjective emotional context responsive to salience and bodily state (Critchley, Mathias, & Dolan, 2002; Goodman, 2008; St-Onge et al., 2014). The OFC was also more responsive to unhealthy food, relative to non-foods (St-Onge et al., 2014), which further demonstrates the role of hedonic stimuli during RES as this brain region is associated with pleasure and hedonic responses (Goodman,
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2008; Gujar et al., 2011; Schloegl et al., 2011), and reward anticipation (Critchley et al., 2002; Rolls, 2004). Given that findings in Chapter Three indicated increased perceived appetite and cravings in conjunction with alterations in hormones suggestive of increased orexigenic signals following sleep restriction, it is plausible that hedonic and homeostatic stimuli work simultaneously to strengthen the drive for food consumption when sleep deprived.

The finding in Chapter Three that FRAG is more detrimental for mood and emotional wellbeing provides further context to previous research conducted by Finan et al. (2015). In the previous study, authors observed a greater reduction in positive mood states (score: ≈ -20 vs -8 from BASE to day three) and heightened negative mood states (score: ≈ +12 vs +10 from BASE to day three) following FRAG (3 nights of forced awakenings at 1 h intervals) compared to RES (3 nights of ≈ 3.5 h sleep) (Finan et al., 2015). It has been suggested that FRAG may induce greater detrimental mood changes, compared to RES, due to the disruption of stage N3 sleep (Finan et al., 2015; Paterson, 2012); although, it is important to acknowledge that shortened sleep also results in negative mood and emotional outcomes (Kahn et al., 2013). Present literature suggests that sleep loss induces concurrent alterations in neural networks whereby inhibitory control over negative mood pathways (e.g. amygdala to medial prefrontal cortex) are diminished (Yoo et al., 2007) and reward-relevant pathways (e.g. mesolimbic) are enhanced towards pleasure-evoking stimuli (Gujar et al., 2011; Schloegl et al., 2011; St-Onge et al., 2014). Moreover, evidence from Walker and Tharani (2009) showed that encoding of memory for neutral and positive experiences are impaired during sleep deprivation, while negative memory is unaffected, suggesting that sleep loss compounds negative-remembering bias (Kahn et al., 2013). When considering this literature, it is possible that the self-reported mood states and mood responses observed in Chapters Three are associated with alterations in brain networks; thus, affecting long-term eating behaviour (increase disinhibition and hunger) and acute food cravings (propensity for sweet foods).
With regard to previous research, individuals who report high disinhibition and hunger are at increased risk of overconsuming sweet and fatty foods, particularly when experiencing high-stress situations and negative mood states, regardless of whether total energy intake is increased, decreased or unchanged (Mercer & Holder, 1997; Oliver & Wardle, 1999; Wang et al., 2001; Wardle, 2007). A possible explanation for this relationship is the interactions of the HPA axis and cortisol which are primary contributors in sleep and appetite regulation, and mood states (Adam & Epel, 2007; Omisade et al., 2010; Pruessner et al., 2005; Pruessner et al., 1999; Sheline et al., 1999; Van Cauter et al., 2000). Elevations in cortisol stimulate the HPA axis which alter anorexigenic effects of several peptides on metabolism, including leptin (Dallman et al., 1993); thus, allowing the anorexigenic peptide induce feelings of satiety (Björntorp, 2001; Zakrzewska et al., 1997). However, chronic high levels of cortisol have been shown to induce excessive circulating leptin, resulting in orexigenic peptides becoming leptin resistant and increasing the risk of obesity (Paspala et al., 2012). Given that there is a natural age-related rise in cortisol which coincides with sleep changes (Van Cauter et al., 2000), it is plausible that these processes compound negative mood states in middle-aged adults leading to increased risk of food overconsumption and development of comorbidities, such as obesity and TIIDM (Adam & Epel, 2007; Kahn et al., 2013; Kredlow et al., 2015; Sharma & Kavuru, 2010). Furthermore, inactive, middle-aged men would appear to require exercise/physical activity interventions which simultaneously consider sleep, appetite and mood outcomes. As participants reported increased stress following consecutive days of EXT in Chapter Three, the solution may not be to increase sleep duration but rather aim to improve sleep quality (e.g. increase stage N3 sleep and reduce number of arousals). Therefore, acute favourable responses from key variables observed in Chapters Three, Four and Five suggest that exercise, particularly of higher intensities, may be a viable intervention for the improvement of sleep, appetite and mood within inactive, middle-aged men.
6.5 Strengths and Limitations

The novel aspect of the current thesis is the concurrent exploration of sleep, appetite and exercise (and mood) within a largely unexplored population (i.e. middle-aged men) using within-subject repeated measures study designs. The aim of the current thesis was to investigate the effects and responses of three primary health-related areas under enforced conditions that either represented real world scenarios (i.e. sleep manipulation protocols) or beneficial interventions (i.e. exercise protocols). Despite these strengths, there are several limitations which need to be acknowledged and may assist the direction for future research. Power analysis indicated that 9 - 11 participants were sufficient to detect significant changes in key variables for each of the respective experimental studies. However, in Chapters Four and Five, we did not observe significant differences in perceived appetite between trials despite significant differences in hormonal markers. As such, it is pertinent for future research to consider larger sample sizes to determine whether there is a disconnect between perceptual and physiological measures of appetite or if the current studies were unable to detect differences due to the smaller sample size. For Chapter Three, all laboratory testing was completed in the morning due to logistical constraints; however, afternoon testing may have resulted in greater between-trial differences in exercise performance, hormone patterns and mood responses due to diurnal hormone variations and extended daytime wakefulness. The hormonal markers for Chapters Three - Five were also measured at very specific time points which were designated to align with capturing acute and prolonged responses to sleep manipulation (Chapter Three) and exercise interventions (Chapters Four and Five). Nonetheless, future research would benefit from more frequent blood sampling across a prolonged time period to more sensitively detect diurnal changes in hormonal markers which may also provide a better explanation for the lack of change in perceived appetite measures. Lastly, there was a large volume of self-reported measures in the current thesis which have been shown to be susceptible to under- and over-reporting of data. These measures were used to reduce the risk of changing the participants’ normal routine and behaviours (i.e. free-living environment). Nonetheless, it may be pertinent for future research to also include non-intrusive
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objective measures to compliment subjective measures of exercise participation/daily physical activity, dietary intake and sleep patterns.

6.6 Conclusions

In conclusion, the innovative findings presented in this thesis demonstrate the complexity of the multi-directional relationship between sleep, diet and exercise, and the role of mood states and emotional wellbeing appears to have on these interactions. Collectively, these studies support the notion that insufficient sleep results in increased negative mood states, impaired appetite-related hormone functions, and the upregulation of perceived appetite and food cravings. Further, while favourable exercise-induced changes in appetite-related hormones were not reflected by subsequent changes in perceived appetite and energy intake; vigorous exercise performed after consecutive nights of insufficient sleep appears to mitigate elevated TMD and the upregulation of desire to consume sweet foods.

For middle-aged adults, the collective data encourages regular exercise for the management of sleep, diet and mood; and rather than discouraging exercise in the early evening, data supports it as a viable exercise time-of-day. Specially, the studies of this thesis have shown that i) both homeostatic (e.g. hormone changes) and hedonic stimuli (e.g. detrimental mood changes) upregulate the drive for calorie-dense food intake when sleep deprived, ii) short-duration, HIE mitigates the amplified negative mood states and drive for food consumption experienced during enforced RES and FRAG, iii) acute HIIE suppresses acylated ghrelin thus reducing orexigenic signals; however, anorexigenic signals, perceived appetite and energy intake appear to be unchanged regardless of exercise intensity or HIIE time-of-day; and iv) early evening HIIE can be performed safely without subsequent detriment to sleep duration or arousal index. The collective findings of this thesis build on current literature examining these respective domains, and promotes the need for holistic management of sleep, diet, exercise and
mood; whereby, the most effective strategies/interventions should consider this multifaceted relationship.
Chapter Seven: Summary and Conclusions
Chapter 7: Summary and Conclusions

7.1 Overview
The primary purpose of this thesis was to examine the physiological, perceptual and behavioural interactions between sleep, appetite and exercise within inactive, middle-aged adults (30 - 65 y). As such, four studies were conducted to explore sleep, eating and exercise behaviours under normal living conditions with consideration for mood states; examine the effects of short-duration, vigorous exercise in mitigating detrimental appetite and mood responses to shortened sleep or disrupted sleep continuity; and the effects of exercise intensity and HIIE time-of-day on sleep characteristics, appetite-related hormones, perceived appetite and energy intake. The outcomes of this research are addressed in each of the thesis aims as follows:

7.2 Thesis Aims:
1. Investigate the effects of prolonged (three consecutive nights) sleep curtailment and extension on appetite-related hormones, perceived appetite and cravings, and mood states in inactive men

The post-sleep manipulation data for Chapter Three showed that prolonged sleep curtailment induced detrimental appetite and mood-related responses within inactive, middle-aged men. In particular, RES was associated with elevated acylated ghrelin and lowered $PYY_{\text{total}}$, increased desire to eat and cravings. Further, RES and FRAG increased TMD compared to CONT and EXT. Unlike we hypothesised, EXT did not induce improvements in either the appetite or mood responses compared to CONT; but rather, was associated with an increase in reported stress. Collectively, these results suggest that improving sleep continuity may be of greater importance for inactive, middle-aged men as opposed to increasing sleep duration, particularly to improve appetite and mood outcomes.
2. Investigate the effects of exercise on appetite-related hormones, perceived appetite and cravings, and mood states following prolonged sleep curtailment and extension in inactive men

In Chapter Three, 20 min of vigorous exercise was associated with an attenuation of detrimental appetite and mood responses to sleep curtailment. Specifically, there was a favourable increase in anorexigenic and decrease in orexigenic peptides from post-sleep manipulation to post-exercise for the RES trial which was further associated with reduced cravings for sweet foods. Likewise, exercise-induced reductions in feelings of tension and TMD were observed for the RES and FRAG trial. As such, it appears that short-duration, vigorous intensity exercise may be utilised for short-term management of appetite and mood variables when sleep deprived. This novel finding further indicates that the exercise-induced mitigation of appetite and mood behaviours, during sleep loss, may reduce overcompensation of sweet foods, thus reducing the short sleep associated impacts on weight management.

3. Investigate the acute effects of exercise intensity and exercise time-of-day on subsequent sleep, appetite-related hormones, and perceived appetite in inactive men

HIIE was shown to induce greater positive changes in sleep and appetite compared to MICE which would appear favourable for improved sleep quality and reduced energy intake. As observed in Chapter Four, there was an increase in stage N3 sleep and reduced number of arousals during REM sleep following HIIE, which may in part be contributed to the high energy demands associated with vigorous exercise and subsequent need for body restoration. Chapter Five indicated that there were no differences in subsequent sleep following HIIE performed at different times of day; however, compared to BASE there was a beneficial increase in stage N3 sleep following MORN, and an increase in NREM sleep and decrease in REM sleep in the initial 180 min of sleep following EVEN. As such, contrary to common opinions, Chapter Five suggests that HIIE can be safely performed at any time of
day without subsequent detriment to sleep duration or arousal index. As for the appetite-related responses, decreases in acylated ghrelin were observed in Chapters Six and Five; although, HIIE performed in the latter half of the day (afternoon and early evening) was associated with greater power output during sprint efforts which may have led to the greater reductions in orexigenic signals. Nevertheless, perceived appetite and free-living energy intake were not associated with these hormone responses suggesting that an acute bout of HIIE may only induce transient appetite responses, and chronic exercise training may be required to stimulate behavioural appetite changes.

7.3 Summary and Conclusions

While previous work has investigated sleep, appetite and exercise behaviours separately, the novel aspect of this thesis was the successful examination of this complex multi-directional relationship simultaneously, while also showing that other factors (mood) influence the interactions of these key domains. The evidence presented in this thesis demonstrates that inactive, middle-aged men are vulnerable to detrimental health outcomes related to negative sleep, appetite, exercise and mood behaviours. Chapter Three further establishes the need to prioritise health interventions which promote sleep continuity rather than extended sleep duration in inactive middle-aged men, while short-duration, vigorous exercise may provide immediate attenuation of the risk of food overconsumption when sleep deprived. Should HIIE training be engaged in habitually, it is plausible that inactive, middle-aged men would experience improvements in sleep, appetite-related signals and mood states (as shown by results in Chapters Six and Five); ultimately, recuperating associated health outcomes. Conclusively, this thesis shows that short-duration, HIIE can be performed safely at any time of day without subsequent detrimental effects on sleep and appetite, thus encouraging exercise participation and eliminating common exercise barriers.
7.4 Practical Applications

- Findings from Chapter Three indicate that vigorous intensity exercise is beneficial for regulating perceived appetite and mood states. As such, engagement in short-duration, vigorous exercise should be performed regularly, even when sleep deprived or experiencing excessive daytime sleepiness, as exercise may mitigate negative appetite and mood states. Further, as shown by Chapter Six and Five, HIIE may promote subsequent sleep improvements and interrupt the deleterious relationship that exists between short sleep or disrupted sleep, ‘unhealthy’ eating behaviour and high TMD.

- Given the greater suppression of appetite post-exercise during HIIE compared to MICE, HIE/HIIE training in conjunction with changes in diet may be most beneficial to improve outcomes of weight loss programs.

- Findings from Chapter Five support HIIE early in the evening as a viable time-of-day for individuals who may experience time-restraints or should this be a preferential time-of-day to engage in exercise.

- Higher power output during sprint efforts were observed for the AFT and EVEN trials in Chapter Five which indicated that participants were able to perform better during the latter half of the day. Therefore, time-of-day should be considered when planning training schedules which utilise HIIE.

- Sleep hygiene practices should focus more on sleep quality as opposed to sleep duration.

7.5 Recommendations for Future Research

- While detrimental appetite- and mood-related responses were observed following consecutive nights of sleep curtailment in Chapter Three, examination of afternoon testing (instead of morning testing) may result in greater changes in hormone patterns and mood responses due to diurnal variations and extended daytime wakefulness.
Chapter 7: Summary and Conclusions

- Given that previous literature has shown that sleep loss interferes with exercise performance among athletes, it may be beneficial to investigate the effects of RES on self-paced exercise to assess perceived effort of exercise intensity and physiological responses during exercise.

- For Chapter Four and Five, HIIE was shown to induce greater changes in sleep and appetite, and that HIIE (regardless of time-of-day) did not negatively affect sleep or appetite variables. However, no significant changes in free-living energy intake were observed for different exercise intensities or exercise times-of-day following a single bout of exercise. Further, acute studies may utilise actigraphy to determine whether post-exercise physical activity decreases following HIIE, particularly within inactive populations who may require greater recovery post-exercise. Investigation of chronic HIIE training effects on sleep and appetite regulation would be advantageous to determine whether the small, transient changes are compounded over time or whether sleep and appetite adapt to long-term training protocols.

- In Chapter Five, requirements of fasting during the MORN, AFT and EVEN trials were different to avoid potential sleep curtailments prior to exercise participation, thus it is possible that this difference influenced hormone responses post-exercise. To determine potential effects of hormonal diurnal patterns on appetite responses to exercise, more frequent blood samples would be required in the hours leading up to and post-exercise.
Chapter Eight: References


Chapter 9: References


Berry, R. B., Brooks, R., & Gamaldo, C. E. (2016). The AASM manual for the scoring of sleep and associated events: Rules, terminology and technical specifications, version 2.3. *American Academy of Sleep Medicine, Darien (IL)*.


Black, A. E., & Cole, T. J. (2001). Biased over- or under-reporting is characteristic of individuals whether over time or by different assessment methods. *Journal of the American Dietetic Association, 101*(1), 70-80. doi: 10.1016/S0002-8223(01)00018-9


Chapter 9: References


Taheri, S., Lin, L., Austin, D., Young, T., & Mignot, E. (2004). Short sleep duration is associated with reduced leptin, elevated ghrelin, and increased body mass index. *Public Library of Science Medicine, 1*(3), 210-217. doi: 10.1371/journal.pmed.0010062


Appendix A:
Ethics Approval Letters, Participant Information, Consent Forms
Appendices

Chapter Three Ethics Approval Letter

22 May 2017

Miss P Larsen
By email: plarsen@csu.edu.au

Dear Miss Larsen,

Thank you for providing additional information in response to a request from the Charles Sturt University Human Research Ethics Committee relating to your research proposal.

The Charles Sturt University Human Research Ethics Committee is constituted and operates in accordance with the National Health and Medical Research Council’s National Statement on Ethical Conduct in Human Research (National Statement).

Based on the guidelines in the National Statement the Committee has approved your research proposal. Please see below details of your research project:

Project Title: Effect of reduced sleep on appetite and exercise behaviour in middle-aged men

Approved until: 31 August 2017 (subject to annual progress reports)

Protocol Number: H17076 (to be included in all correspondence to the Committee)


You must report to the Committee at least annually, and as soon as possible in relation to the following, by completing the ‘Report on Research Project’ form:

- any serious and/or unexpected adverse events or outcomes which occur associated with the research project that might affect participants, therefore, the ethical acceptability of the project;
- amendments to the research design and/or any changes to the project (Committee approval required);
- extensions to the approval period (Committee approval required); and
- notification of project completion.

This approval constitutes ethical approval in relation to humans only. If your research involves the use of radiation, biochemical materials, chemicals or animals, separate approval is required by the appropriate University Committee.
Please contact the Governance Office on (02) 6338 4626 or ethics@csu.edu.au if you have any queries.

The Committee wishes you well with your research.

Sincerely

Mrs Sue Price
Governance Officer

Cc: Dr Melissa Skein, Professor Frank Marino, Associate Professor Rob Duffield, Dr Kym Guelfi
Chapter Three Participant Information

Information Sheet

Title: Effect of reduced sleep on appetite and exercise behaviour in middle-aged men

Primary Investigator
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You have been invited to participate in a research study. Participation in this study is entirely voluntary. You may decide not to participate, or may withdraw from the study at any time. Information obtained from you or about you during this study which could identify you will be kept confidential by the researchers. The researchers will be available during the study at all times if you have any problems or questions about the nature or conduct of the study.

Purpose of the Study
This study is being conducted and undertaken by Penelope Larsen (PhD student) to fulfil the requirements to obtain her Doctorate of Philosophy. The information from this study will be included in Penelope’s thesis and future manuscript publications.

The aim of this study is to investigate the acute effect of sleep quality and quantity in middle-aged men on:

- Sleep-related hormones (i.e. melatonin and cortisol);
- Eating behaviour and appetite-related hormones (i.e. acetylated ghrelin – increases hunger and drive to eat, and leptin and PYY – increases satiety or fullness);
- Exercise performance (self-paced cycling) and motivation;
- Mood states.

This study will examine the short-term outcomes of sleep deprivation and disruption, and sleep extension on the above variables. This study aims to evaluate the changes of appetite, metabolism, exercise performance and motivation, and mood related to altered sleep which may indicate potentiating risk of future disease, such as cardiovascular disease, diabetes and/or obesity.
Appendices

Study Procedures and Protocol

This study can be completed within 5 weeks. Prior to study commencement, Penelope will arrange a time schedule that suits both the participant and the researchers. The testing can be completed over 5 consecutive weeks or spread between the months of June and July. All data collection will be conducted at the CSU Exercise Physiology Laboratories. Participants will be required to complete 5 data collection sessions. The first session will include a familiarisation to ensure participants know all processes and equipment before starting the study. As shown in Figure 1, each of the remaining four (4) conditions will include the manipulation of three (3) night’s sleep followed by completion of testing, in the morning (0730-1000 h). Sleep conditions will be completed at home and will include (and will be completed in a randomised order):

1) Control (normal) sleep (CONT): approximately 6-8.5 hours sleep.
2) Sleep restriction (RES): approximately 4 hours sleep. Participants will be required to stay awake until 2am and set an alarm to wake at 6am. This condition is designed to reduce sleep quantity compared to CONT.
3) Sleep extension (EXT): approximately 10 hours sleep. Participants will be required to go to bed at 9pm and stay in bed until 7am, preferably asleep for the entire duration. This condition is designed to increase sleep quantity compared to CONT.
4) Sleep fragmentation (FRA): approximately 6-8.5 hours sleep. Participants will be required to go to bed at 9pm and stay in bed until 5am; however an alarm will need to be set at 11pm, 1am, 3am and 5am to force the participant to wake, turn off their alarm before returning to sleep. This condition is designed to reduce sleep quality compared to CONT.

You will be required to wear an Actiwatch, and report sleep and food intake (diary provided) from 6pm on the first evening of each sleep intervention until conclusion of testing to ensure you have complied with your assigned sleep condition. An Actiwatch is a device similar to a Fitbit that will be worn on your right wrist. The watch is pre-programmed as to when to start and finish data collection. We remind you that the Actiwatchs are quite expensive and should be handled with care. There will not be any cost to the participant if the watch is damaged or stolen. In addition, participants will be required to avoid napping during the day while undertaking the sleep intervention and on the day of testing.

Participants will attend the CSU Exercise Physiology Laboratories, the morning following the sleep intervention and complete testing. All testing will take no more than 90 min to complete and include:

a) A fasting capillary (from the fingertip) blood draw for the assessment of key appetite-related hormones (i.e. acylated ghrelin, leptin, PYY1-36).

b) Cognition will be assessed using a modified Stroop Task which will include identifying correct colours on a computer screen and making the appropriate keystroke response in the shortest duration possible.

c) Perceptual measures will include a visual analogue scale for perceived hunger and fullness, and 2 questionnaires relating to mood states and wellness.

d) A performance test which will include 20 min of self-paced cycling on a Wattbike with a standardized resistance of 4. This testing is for the assessment of heart rate and power output.
Figure 1: Overview of study design

Eligibility
We are recruiting men aged 35-60 years old for this study. To be eligible you must fit the following criteria:
- Never been diagnosed with a sleep disorder, e.g. sleep apnoea or insomnia.
- Achieving 6-8.5 hours of sleep most nights.
- Not on any medication that may affect sleep.
- Inactive: not engaging in more than 150 min of exercise per week.
- Free from any conditions which may be exacerbated by reduced sleep or exercise.
- Non-smoker.
- Available for testing during JUNE-JULY 2017.

Volunteers will also be required to complete two short questionnaires to assess risk of sleep apnoea and exercise readiness. Should there be evidence of high risk sleep apnoea volunteers will be excluded from the study. Additionally, should there be an indication of a health condition which may be exacerbated by exercise, volunteers may be required to obtain GP clearance prior to study commencement or be excluded from the study.

Possible Discomfort or Inconvenience
This study is non-invasive therefore there should be very little risks to the participants. The utmost care will be taken to ensure participants’ safety during all procedures of this study. However, if participants suffer possible discomfort, they have the right to refuse to answer questions, and withdraw from the study at any time. Furthermore, in the case of an emergency, Penelope is qualified to provide first aid and an ambulance will be called depending on the severity of the situation. Penelope will also follow-up to ensure the participant is well and no further action is required.

It should be noted that participants may experience increased drowsiness, fatigue, and/or irritability during the sleep restriction and sleep fragmentation interventions. Therefore, participants should avoid tasks that require high levels of concentration for a prolonged period of time, such as operating heavy machinery and driving, or making decisions of high importance. Should transportation to the laboratories be required, please notify the research team.
Confidentiality
The privacy of all volunteers will be assured and all data acquired from individual participants will be kept strictly confidential on password-protected computers. Only the Primary Investigator and Research Supervisors will have access to participant's identities.

During data collection, video footage and photographs will be taken of the procedures and exercise protocols for future use in conference presentations and Penelope's thesis. Precautions will be taken to ensure that participants will not be identifiable. However, all participants have the right to refuse permission to have video footage or photographs taken during data collection. Participants will be asked to provide permission (should they wish to) on the study Consent Form.

Coercion and Withdrawal
You have the right to participate in this investigation without the intervention of any element of force, fraud, deceit, duress, coercion, or undue influence on your decision. In the event that you agree to participate you have the right to withdraw your consent and cease involvement in the investigation at any time without consequence. If you choose to withdraw from the study, you will also have the right to withdraw any information or data that has been obtained from you. This is regardless of whether you have completed all stages of the study or only partial stages.

Liability Statement
Your signature indicates your consent and that you understand the information regarding the research study. In no way does this waive your legal rights nor release the investigators or Charles Sturt University from their legal and professional responsibilities.

NOTE: Charles Sturt University's Human Research Ethics Committee has approved this project. If you have any complaints or concerns about the ethical conduct of this project, you may contact the Committee through:

The Executive Officer
Human Research Ethics Committee
Academic Secretariat
Charles Sturt University
Private Mail Bag 29
Bathurst NSW 2795
Tel: (02) 6398 4858
Email: ethics@csu.edu.au

Any issues you raise will be treated in confidence and investigated fully and you will be informed of the outcome.
Chapter Three Consent Form

**Informed Consent**

**Title:** Effect of reduced sleep on appetite and exercise behaviour in middle-aged men

**Investigator Responsibilities - Participant Rights**
1. As a subject you are free to withdraw your consent to participate at any time.
2. The researchers will answer any questions you may have in regard to the study at any time.

**Supervisors**
- **Principal Investigator:** P. Larse
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- **Dr. K. Gueli**
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  - Crawley, WA
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  - Email: kym.gueli@uwa.edu.au

**Explanation & Understanding of Study Procedures**

I have been provided with sufficient information on the study, including that:
- The study will be conducted as described in the Information Sheet, a copy of which I have retained.
- I can withdraw from the study at any time and do not have to give any reason for withdrawing.
- My confidentiality will be preserved and I understand how data collected from me will be used during and after my involvement in the study.
- I give my permission for photographs or video footage during my data collection period. I understand that these may be used for academic presentations (i.e. conferences), however, all persons will be de-identifiable.

I, (print your name) ___________________________ have read the information contained within this consent form and any questions I have asked have been answered to my satisfaction.

____________________  ________________
Signature of Participant  Date

____________________  ________________
Signature of Primary Investigator  Date

**NOTE:** Charles Sturt University’s Human Research Ethics Committee has approved this project. If you have any complaints or concerns about the ethical conduct of this project, you may contact the Committee through:

- **The Executive Officer**
  - Human Research Ethics Committee
  - Academic Secretariat
  - Charles Sturt University
  - Private Mail Bag 29
  - Bathurst NSW 2795
  - Tel: (02) 6338 4628
  - Email: ethics@csu.edu.au

Any issues you raise will be treated in confidence and investigated fully and you will be informed of the outcome.
Appendices

Chapters Four and Five Ethics Approval Letter

13 September 2018

Miss Penelope Larsen
School of Exercise Science, Sport & Health
Charles Sturt University
Panorama Avenue
BATHURST NSW 2795

Dear Miss Larsen,

Thank you for the additional information forwarded in response to a request from the Charles Sturt University (CSU) Human Research Ethics Committee (HREC).

The CSU HREC reviews projects in accordance with the National Health and Medical Research Council’s National Statement on Ethical Conduct in Research Involving Humans.

I am pleased to advise that your project entitled “The effect of exercise mode and time-of-day on sleep quality and quantity, appetite hormones and eating behaviour” meets the requirements of the National Statement, and ethical approval for this research is granted for a twelve-month period from the date of this letter.

The protocol number issued with respect to this project is H16136. Please be sure to quote this number when responding to any request made by the Committee.

Please note the following conditions of approval:

- all Consent Forms and Information Sheets are to be printed on Charles Sturt University letterhead. Students should liaise with their Supervisor to arrange to have these documents printed;
- you must notify the Committee immediately in writing should your research differ in any way from that proposed. Forms are available at: http://www.csu.edu.au/__data/assets/word_doc/0007/63763/Report-on-Research-Project_20130603.doc (please copy and paste the address into your browser);
- you must notify the Committee immediately if any serious and or unexpected adverse events or outcomes occur associated with your research, that might affect the participants and therefore ethical acceptability of the project. An Adverse Incident form is available from the website as above;
- amendments to the research design must be reviewed and approved by the Human Research Ethics Committee before commencement. Forms are available at the website above;
- if an extension of the approval period is required, a request must be submitted to the Human Research Ethics Committee. Forms are available at the website above;
- you are required to complete a Report On Research Project, which can be downloaded as above, by 21/07/2017 if your research has not been completed by that date;
- you are required to submit a final report. The form is available from the website above.

YOU ARE REMINDED THAT AN APPROVAL LETTER FROM THE CSU HREC CONSTITUTES ETHICAL APPROVAL ONLY.

If your research involves the use of radiation, biological materials, chemicals or animals a separate approval is required from the appropriate University Committee.

www.csu.edu.au

Australian Provider Numbers for Charles Sturt University are 000105* (NSW), CH1407 (VIC) and 02930D (NT). ABN: 53 070 709 551
The Committee wishes you well in your research and please do not hesitate to contact the Governance Officer on telephone (02) 6338 4628 or email ethics@csu.edu.au if you have any enquiries.

Yours sincerely

Regan McIntosh  
Governance Officer  
Human Research Ethics Committee  
Direct Telephone: (02) 6338 4628  
Email: ethics@csu.edu.au

Cc: Dr Melissa Skein, Professor Frank Marino, Associate Professor Rob Duffield and Dr Kym Guelfi

The Charles Sturt University Human Research Ethics Committee is constituted and operates in accordance with the National Health and Medical Research Council’s (NHMRC) National Statement on Ethical Conduct in Human Research (2007)
Appendices

Chapters Four and Five Participant Information

Information Sheet

Title: The effect of exercise mode and time-of-day on sleep quality and quantity, appetite hormones and eating behaviour

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Overview

This study is being conducted for the purpose of Penelope’s PhD Thesis investigating the relationship between sleep, exercise and appetite. Before deciding to volunteer for this study, we ask that you read the following information to understand the purpose, protocol, and responsibilities as a participant. If you have any queries regarding the study you can direct these to Penelope or Dr Melissa Skaie as Penelope’s primary supervisor via the details above.

Purpose of the Study

Exercise is strongly believed to be a key promoter of sleep quality and quantity, and moderator of energy intake and energy expenditure. Therefore, the aims of this study is to: (1) examine the effects of exercise mode (i.e. MICE, moderate-intensity continuous exercise, and HIE, high intensity interval exercise) on sleep quality and quantity, the time-course of appetite-related hormones, and eating behaviour, and (2) examine the effects of exercise time-of-day (i.e. morning vs. evening) on sleep quality and quantity, the time-course of appetite-related hormones, and eating behaviour.

Participant Inclusion Criteria

To be eligible for this study, you must meet the following criteria:

- Male aged 35-60 years
- No current or previous sleep apnoea diagnosis
- Not engaged in work or recreational activities that significantly alter sleep patterns (i.e. shift work)
- No known medical conditions or medications that affect sleep quality and/or quantity
- Not on medication for appetite control or weight loss
- Not engaged in more than 150min/week of moderate-intensity exercise
- Free from known stable or unstable cardiovascular/heart disease
- No previous diagnosis of type II diabetes mellitus, respiratory conditions or orthopaedic limitations
- Not a current smoker, or a smoker who has quit in the past 12 months
- Free from current illness such as the flu
- Not currently being treated for dental diseases
Figure legend: SAQ, Sleep apnoea questionnaires; PEMHI, Pre-Exercise Medical Health Questionnaire; HT, height; WT, weight; W/H, waist-to-hip circumference; DKA, dual-energy x-ray scan; PSCI, Pittsburgh Sleep Quality Index; TFEQ, Three-Factor Eating Questionnaire; FCCQ-T, Food Cravings Questionnaire - Trait; PCMS, Profile of Mood States; FSS, Fatigue Severity Scale; GXT, graded exercise test; PSG, polysomnography (sleep testing); ↔ visual analogue scale for hunger and fullness; ⚫ capillary blood sample; ⚫ saliva sample; MICT, moderate-intensity continuous exercise; HIIE, high-intensity interval exercise; FCCQ-S, Food Cravings Questionnaire - State.
Pre-screening

Initially, participants will complete two validated questionnaires, the STOP-BANG Questionnaire and the Epworth Sleepiness Scale to assess their risk of sleep apnoea. If these questionnaires indicate that the participant is at high-risk of the condition, they will be excluded from the study and encouraged to see their General Practitioner (GP) for further testing. Also, this study requires participants to perform high-intensity exercise; therefore, they will be required to obtain medical clearance from their GP and complete a Pre-Exercise Medical Health Questionnaire prior to testing.

Familiarisation

Participants will be required to attend the Exercise Physiology laboratories at Charles Sturt University (CSU) for approximately 1½ hours to obtain several baseline measures. During this laboratory session, anthropometry measures (i.e. height, weight, waist and hip circumference) will be recorded; and complete the Pittsburgh Sleep Quality Index, Three-Factor Eating Questionnaire, Food Cravings Questionnaire - Trait, and the Profile of Mood States which will assess subjective sleep quality, eating behaviour, general food cravings and transient mood states, respectively. Also, participants will perform a maximal graded exercise test on a stationary bike to assess cardiovascular fitness and calculate workloads for the four (4) exercise conditions.

The week following familiarisation testing, participants will be equipped with a take-home polysomnography (PSG) unit which will be used to record sleep quality for two nights (for further information see Equipment and Procedural Information). This data will be used to obtain baseline sleep quality and confirm the absence of sleep apnoea. If sleep apnoea is detected from this sleep testing, the participant will be excluded from the study and referred to their GP for further assessment. Participants will also be equipped with an Actiwatch and 7-day diary for subjective sleep assessment, diet and physical activity (for further information see Equipment and Procedural Information). This data will be used to assess participants’ general sleep, eating, and activity behaviour to compare with changes following the four exercise conditions.

Testing Conditions

Each condition will involve two visits to the laboratories and one out-of-lab recording. The first visit of each condition will involve 30 minutes of exercise and 30 minutes of rest. Participants will need to allow approximately 1½ hours to account for exercise preparation and post-exercise measures. The second visit to the laboratories will be the morning after exercise to obtain a capillary blood sample. This should take no longer than 20 minutes.

The two exercise modes participants will complete are: (1) moderate-intensity continuous exercise (MICE), and (2) high-intensity interval exercise (HIIE) which will be conducted on a stationary bike (for further information see Equipment and Procedural Information). While exercising, participants’ heart rate, power output and rating of perceived exertion (i.e. ‘how hard’ the exercise was) will be monitored. The MICE will
be completed once by each participant between 1400-1600 h, and the HIIE will be completed on 3 separate occasions between 0600-0700 h, 1400-1600 h, and 1900-2000 h.

The day prior to each exercise session, participants will be equipped with an Actiwatch and a 4-day diary for subjective sleep assessment, diet and physical activity. Before leaving the laboratory post-exercise, participants will also be equipped with a take-home PSG unit for one night. In addition, participants will be asked to collect a saliva sample immediately before bed and immediately following wake time (for further information see Equipment and Procedural Information) on the evening following exercise. Samples will be collected by Penelope to ensure that they are protect during transportation back to the laboratories for storage until further analysis.

Equipment and Procedural Information

Take-Home Polysomnography (PSG) Unit: The device which will be used for this study is called an Alice PDX and it is approximately the size of a glass’s case. The main device is positioned on the mid-chest region (in line with the sternum) and secured by a chest strap. Electrodes will be placed on the skull, forehead and chin to attach leads from the device to specific regions of the head. Participants will also have a lead attached to their pointer finger. The information recorded from the device will include brain wave activity, eye movement, muscle tone and oxygen saturation. The sleep variables that will be assessed from this information include sleep stages, sleep cycles, and sleep fragmentation. You will be provided an information booklet in addition to a physical demonstration outlining how to wear the device and start and stop recording.

Actiwatch: This is a non-intrusive device which looks similar to a Fit-Bit and worn on the wrist. The device monitors activity/movement and will be used to measure sleep variables on nights when PSG is not being recorded. The device is to be worn at all times except when bathing or engaged in heavy duty activities. The information obtained will be used to examine sleep latency, sleep efficiency, wake after sleep onset, time in bed, total sleep time, and number of awakenings.

Participant Booklet: Each participant will receive a booklet that will contain all information, instructions and recording sheets to complete the study. The booklet will contain important contact details, a calendar for participants' testing days, instructions for each condition (i.e. preparation, what to wear and bring to testing), recording sheets for familiarisation, baseline assessment, and the four conditions included in the booklet is the diary for subjective sleep assessment, diet and physical activity. Participants will be asked to complete all sections of their diary during the 7-days of baseline and 4-days of each condition.

Capillary Blood Samples: This blood drawing technique will involve soaking the hand in warm water before making a small laceration on a fingertip to draw < 1mL of blood. For each condition, 3 samples will be drawn at these time-points: pre-exercise, 30 minutes post-exercise and the morning post-exercise. The plasma extracted from the blood samples will be used to analysis the concentration of a number of appetite
related hormones. If you have experienced adverse reactions to giving blood, please advise Penelope of this so that appropriate precautions can be taken.

Saliva Samples: To obtain saliva samples, participants will be required to drool into a tube. Two samples will be collected at each time-point which is immediately prior to bedtime and immediately after waking the night following exercise. Specific instructions for taking the saliva sample will be provided in the Participant Handbook. Participants will be asked to store the saliva samples in their home freezer until Penelope can collect them to transport them appropriately back to the CSU laboratories. The saliva samples will be analysed for the concentration of melatonin before and after sleep following exercise.

Subjective Appetite Assessment: Participants will indicate their perceived hunger and fullness on a 100mm visual analogue scale (VAS) at pre-exercise, 30 minutes post-exercise and the morning post-exercise. This data will be examined against the data for appetite-related hormone concentrations.

Participant Responsibilities

- For this study each participant will need to be available for October and November, 2016. During these two months, participants will be required to attend the CSU laboratories once a week. Participants will receive one week of no testing after completing two conditions. This study is time sensitive due to hiring of equipment and will need to be completed by the end of November. If you are unsure that you can commit to being available for these two months, please discuss with the principal investigator.

- The cost of the GP appointment will be at the discretion of participants. However, this appointment should be similar to a general check-up which may be covered by Medicare.

- We ask that participants are prompt to all laboratory sessions. If an issue arises, please notify Penelope as soon as possible - 0423 911 625. Issues may include sudden illness, family commitments or work-related matters.

- It is important that participants follow all instructions regarding the preparation for each of the conditions and exercises bouts, as each condition will require slightly different preparation.

- It is the participant’s responsibility to take care of all equipment provided to them for the purpose of this study. Should any equipment be damaged from negligent behaviour, it may be the responsibility of the participant to pay for the costs of repair or replacement which could be upwards of $1,500.

- Self-reporting must be done to the best of the participant’s ability. As such, we ask that participants are attentive when self-reporting and follow all instruction. To be most accurate with reporting, we recommend that participants record at the time of the event or shortly after.
Confidentiality

Any information obtained which may identify you will be coded and only identifiable to the researchers. This will be stored securely and only accessed by the researchers unless you gave consent otherwise, except as required by law. Data will be retained for at least 5 years under lock and key, username/passwords, etc. at Charles Sturt University, Bathurst. It is the purpose of the research to be published as part of Ms Larsen’s PhD thesis and two research manuscripts in a scientific journal, however your individual information will not be identified via this publication process. Photos and video footage will be taken of procedures conducted during the study for the use in presentations at conferences and seminars. All imagery of participants will ensure faces are pixelated or covered to avoid potential identification. However, as stated in the accompanying informed Consent Form, you may refuse to have photos or video footage taken of you during your participation in this research study.

Withdrawal Process

A participant can withdraw from this study for any reason without explanation. If this occurs, your data will not be used in the research, thus not included in any publications that come from this research. Electronic data will be deleted from all sources such as the researcher’s hard drive; and paper data will be shredded and disposed of appropriately. If you withdraw due to ethical reasons, you may also wish to contact the Human Research Ethics Committee. Contact details are listed below.

NOTE: Charles Sturt University’s Human Research Ethics Committee has approved this project. If you have any complaints or concerns about the ethical conduct of this project, you may contact the Committee through:

The Executive Officer
Human Research Ethics Committee
Office of Governance and Corporate Affairs Charles Sturt University
Private Mail Bag 29 Panorama Avenue
Bathurst NSW 2795
Tel: (02) 6338 4628
Email: ethics@csu.edu.au

Any issues you raise will be treated in confidence and investigated fully and you will be informed of the outcome.
Appendices

Chapters Four and Five Consent Form

Informed Consent

Title: The effect of exercise mode and time-of-day on sleep quality and quantity, appetite hormones and eating behaviour

Investigator Responsibilities - Participant Rights
1. As a subject you are free to withdraw your consent to participate at any time.
2. The researchers will answer any questions you may have in regard to the study at any time.

Any questions concerning the study can be directed to:

Primary Investigator
Mr Penelope Larsen (PhD Student)
School of Exercise Science, Sport & Health
Charles Sturt University
Panorama Ave, Bathurst
Tel: (02) 6338 6101 or 0423 911 625
Email: plarsen@csu.edu.au

Supervisor
Dr Melissa Skain
School of Exercise Science, Sport & Health
Charles Sturt University
Panorama Ave, Bathurst
Tel: (02) 6338 4430
Email: mskain@csu.edu.au

Prof Frank Marino
School of Exercise Science, Sport & Health
Charles Sturt University
Panorama Ave, Bathurst
Tel: (02) 6338 4168
Email: fmarino@csu.edu.au

A/Prof Rob Duffield
Sport & Exercise Discipline
University of Technology Sydney
Broadway, Sydney
Tel: (02) 9514 5294
Email: Rob.Duffield@uts.edu.au

Dr Kym Guelfi
School of Sport Science, Exercise & Health
The University of Western Australia
Crawley, WA
Tel: (08) 6488 2602
Email: kym.guelfi@uwa.edu.au

Explanation & Understanding of Study Procedures
I have been provided with sufficient information on the study, including that:

☐ I agree to participate in the above research project and give my consent freely;
☐ The study will be conducted as described in the Information Sheet, a copy of which I have retained;
☐ I agree to pay for the repair or purchase of an Actiwatch should it be damaged or lost due to my negligence;
☐ I can withdraw from the study at any time and do not have to give any reason for withdrawing;
☐ My confidentiality will be preserved and I understand how data collected from me will be used during and after my involvement in this study.
☐ I give my permission for photograph or video footage during my data collection period. I understand that these may be used for academic presentations (i.e. conferences); however, all persons will be de-identifiable.

I, (print your name) __________________________________________ have read the information contained within this consent form and any questions I have asked have been answered to my satisfaction.

__________________________
Signature of Participant

__________________________
Signature of Primary Investigator

Date

Date
Values and Principles of Ethical Conduct

NOTE: Charles Sturt University’s Human Research Ethics Committee has approved this project. If you have any complaints or reservations about the ethical conduct of this project, you may contact the Committee through:

The Executive Officer
Human Research Ethics Committee
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Private Mail Bag 29 Panorama Avenue
Bathurst NSW 2795

Tel: (02) 6338 4628
Email: ethics@csu.edu.au

Any issues you raise will be treated in confidence and investigated fully and you will be informed of the outcome.
Appendix B:

Questionnaires, Pre-Screening, Perceptual Scales
Appendices

Three Factor Eating Questionnaire - with Scoring

Three Factor Eating Questionnaire

Please indicate ‘true’ or ‘false’ to indicate whether or not the following statements are true to you.
Note: Try not to over think each question.

1. When I smell a sizzling steak or see a juicy piece of meat, I find it very difficult to stop myself from eating, even if I have just finished a meal.
2. I usually eat too much at social occasions, like parties and picnics.
3. I am usually so hungry that I eat more than three times a day.
4. When I have eaten my quota of calories, I am usually good about not eating any more.
5. Dieting is so hard for me because I just get too hungry.
6. I deliberately take small helpings as a mean of controlling my weight.
7. Sometimes things just taste so good that I keep on eating even when I am no longer hungry.
8. Since I am often hungry, I sometimes wish that while I am eating, an expert would tell me that I have had enough or that I can have something more to eat.
9. When I feel anxious, I find myself eating.
10. Life is too short to worry about dieting.
11. Since my weight goes up and down, I have gone on diets more than once.
12. I often feel so hungry that I just have to eat something.
13. When I am with someone who is overeating, I usually overeat too.
14. I have a pretty good idea of the number of calories in common foods.
15. Sometimes when I start eating, I just can’t seem to stop.
16. It is not difficult for me to leave something on my plate.
17. At certain times of the day, I get hungry because I have gotten used to eating then.
18. While on a diet, if I eat food that is not allowed, I consciously eat less for a period of time to make up for it.
19. Being with someone who is eating often makes me hungry enough to eat also.
20. When I feel blue, I often overeat.
21. I enjoy eating too much to spoil it by counting calories and watching my weight.
22. When I see a real delicacy, I often get so hungry that I have to eat right away.
23. I often stop eating when I am not really full as a conscious means of limiting the amount that I eat.
24. I get so hungry that my stomach often seems like a bottomless pit.
25. My weight has hardly changed at all in the last ten years.
26. I am always hungry so it is hard for me to stop eating before I finish the food on my plate.  
27. When I feel lonely, I console myself by eating.  
28. I consciously hold back at meals in order not to gain weight.  
29. I sometimes get very hungry late in the evening or at night.  
30. I eat anything I want, any time I want.  
31. Without even thinking about it, I take a long time to eat.  
32. I count calories as a conscious means of controlling my weight.  
33. I do not eat some foods because they make me fat.  
34. I am always hungry enough to eat at any time.  
35. I pay a great deal of attention to changes in my shape.  
36. While on a diet, I eat a food that is not allowed, I often then splurge and eat other high calorie foods.

Please answer the following questions by circling the number above/next to the response that is appropriate to you.

<table>
<thead>
<tr>
<th>Question</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>37. How often are you dieting in a conscious effort to control your weight?</td>
<td>Rarely</td>
<td>Sometimes</td>
<td>Usually</td>
<td>Always</td>
</tr>
<tr>
<td>38. Would a weight fluctuation of 2-3kg affect the way you live your life?</td>
<td>Not at all</td>
<td>Slightly</td>
<td>Moderately</td>
<td>Very much</td>
</tr>
<tr>
<td>39. How often do you feel hungry?</td>
<td>Only at mealtimes</td>
<td>Sometimes between meals</td>
<td>Often between meals</td>
<td>Almost always</td>
</tr>
<tr>
<td>40. Do your feelings of guilt about overeating help you to control your food intake?</td>
<td>Never</td>
<td>Rarely</td>
<td>Often</td>
<td>Always</td>
</tr>
<tr>
<td>41. How difficult would it be for you to stop eating halfway through dinner and not eat for the next four hours?</td>
<td>Easy</td>
<td>Slightly difficult</td>
<td>Moderately difficult</td>
<td>Very difficult</td>
</tr>
<tr>
<td>42. How conscious are you of what you eat?</td>
<td>Not at all</td>
<td>Slightly</td>
<td>Moderately</td>
<td>Extremely</td>
</tr>
</tbody>
</table>
### Appendixes

#### Questionnaire

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>43. How frequently do you avoid having tempting foods in the house?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Almost never</td>
<td>Seldom</td>
<td></td>
</tr>
<tr>
<td>2. Seldom</td>
<td>Usually</td>
<td></td>
</tr>
<tr>
<td>3. Usually</td>
<td>Almost always</td>
<td></td>
</tr>
<tr>
<td>4. Usually</td>
<td></td>
<td></td>
</tr>
<tr>
<td>44. How likely are you to shop for low calorie foods?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Unlikely</td>
<td>Slightly likely</td>
<td></td>
</tr>
<tr>
<td>2. Slightly likely</td>
<td>Moderately likely</td>
<td></td>
</tr>
<tr>
<td>3. Moderately likely</td>
<td>Very likely</td>
<td></td>
</tr>
<tr>
<td>4. Very likely</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45. Do you eat sensibly in front of others and splurge when you are alone?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Never</td>
<td>Rarely</td>
<td></td>
</tr>
<tr>
<td>2. Rarely</td>
<td>Often</td>
<td></td>
</tr>
<tr>
<td>3. Often</td>
<td>Always</td>
<td></td>
</tr>
<tr>
<td>4. Always</td>
<td></td>
<td></td>
</tr>
<tr>
<td>46. How likely are you to consciously eat slowly in order to cut down on how much you eat?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Unlikely</td>
<td>Slightly likely</td>
<td></td>
</tr>
<tr>
<td>2. Slightly likely</td>
<td>Moderately likely</td>
<td></td>
</tr>
<tr>
<td>3. Moderately likely</td>
<td>Very likely</td>
<td></td>
</tr>
<tr>
<td>4. Very likely</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47. How frequently do you skip dessert because you are no longer hungry?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Almost never</td>
<td>Seldom</td>
<td></td>
</tr>
<tr>
<td>2. Seldom</td>
<td>At least once a week</td>
<td></td>
</tr>
<tr>
<td>3. At least once a week</td>
<td>Almost every day</td>
<td></td>
</tr>
<tr>
<td>4. Almost every day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>48. How likely are you to consciously eat less than you want?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Unlikely</td>
<td>Slightly likely</td>
<td></td>
</tr>
<tr>
<td>2. Slightly likely</td>
<td>Moderately likely</td>
<td></td>
</tr>
<tr>
<td>3. Moderately likely</td>
<td>Very likely</td>
<td></td>
</tr>
<tr>
<td>4. Very likely</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49. Do you go on eating binges even though you are not hungry?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Never</td>
<td>Rarely</td>
<td></td>
</tr>
<tr>
<td>2. Rarely</td>
<td>Sometimes</td>
<td></td>
</tr>
<tr>
<td>3. Sometimes</td>
<td>At least once a week</td>
<td></td>
</tr>
<tr>
<td>4. At least once a week</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50. On a scale from 0 to 5, how much restraint do you think you have with regards to eating?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0. Eat whatever you want, whenever you want it (no restraint)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Usually eat whatever you want, whenever you want it</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Often eat whatever you want, whenever you want it</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Often limit your food intake but often ‘give in’</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Usually limit your food intake and rarely ‘give in’</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Constantly limit your food intake and never ‘give in’ (total restraint)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Constantly limit your food intake and never ‘give in’ (total restraint)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>51. To what extent does the following statement describe your eating behaviour:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“I start dieting in the morning, but because of any number of things that happen during the day, by evening I have given up and eat what I want, promising myself to start dieting again tomorrow.”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Not like me</td>
<td>A little like me</td>
<td></td>
</tr>
<tr>
<td>2. A little like me</td>
<td>Pretty good description of me</td>
<td></td>
</tr>
<tr>
<td>3. Pretty good description of me</td>
<td>Describes me perfectly</td>
<td></td>
</tr>
<tr>
<td>4. Describes me perfectly</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Pittsburgh Sleep Quality Index

Instructions: The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions:

1. What time do you usually get into bed? ____________
2. How long (in minutes) has it taken you to fall asleep each night? ____________
3. What time do you usually wake in the morning? ____________
4. How many hours of actual sleep do you get at night? ____________ (This may be different than the number of hours you spend in bed)

5. During the past month, how often have you had trouble sleeping because you...
   a. Cannot get to sleep within 30 mins
   b. Wake up in the middle of the night or early morning
   c. Have to get up to use the bathroom
   d. Cannot breathe comfortably
   e. Cough or snore loudly
   f. Feel too cold
   g. Feel too hot
   h. Have bad dreams
   i. Have pain
   j. Other reason(s), please describe, including how often you have had trouble because of this reason(s):

<table>
<thead>
<tr>
<th>Not during the past month (0)</th>
<th>Less than once a week (1)</th>
<th>Once or twice a week (2)</th>
<th>Three or more times a week (3)</th>
</tr>
</thead>
</table>

6. During the past month, how often have you taken medicine (prescribed or “over the counter”) to help you sleep?

7. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

8. During the past month, how much of a problem has it been for you to keep up enthusiasm to get things done?

   Very good (0) | Fairly good (1) | Fairly bad (2) | Very bad (3)

9. During the past month, how would you rate your sleep quality overall?
### Pittsburgh Sleep Quality Index - Scoring System

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component 1</td>
<td>#9 Score</td>
<td>[ \text{C1} ]</td>
</tr>
<tr>
<td>Component 2</td>
<td>#2 Score (( \leq 15 \text{ min} = 0 ); 16-30 min = 1; 31-60 min = 2; &gt;60 min = 3) + #5a Score (if sum is equal 0 = 0; 1-2 = 1; 3-4 = 2; 5-6 = 3)</td>
<td>[ \text{C2} ]</td>
</tr>
<tr>
<td>Component 3</td>
<td>#4 Score (( &gt; 7 = 0 ); 6-7 = 1; 5-6 = 2; ( &lt; 5 ) = 3)</td>
<td>[ \text{C3} ]</td>
</tr>
<tr>
<td>Component 4</td>
<td>(total # of hours asleep)/(total # of hours in bed) x 100 ( &gt; 85% = 0 ); 75%-84% = 1; 65%-74% = 2; ( &lt; 65% ) = 3</td>
<td>[ \text{C4} ]</td>
</tr>
<tr>
<td>Component 5</td>
<td>Sum of Scores #5b to #5j (0 = 0; 1-9 = 1; 10-18 = 2; 19-27 = 3)</td>
<td>[ \text{C5} ]</td>
</tr>
<tr>
<td>Component 6</td>
<td>#6 Score</td>
<td>[ \text{C6} ]</td>
</tr>
<tr>
<td>Component 7</td>
<td>#7 Score + #8 Score (0 = 0; 1-2 = 1; 3-4 = 2; 5-6 = 3)</td>
<td>[ \text{C7} ]</td>
</tr>
</tbody>
</table>

Add the seven component scores together \[ \text{Global PSQI Score} \]
**Perceived Stress Scale**

The questions in this scale ask you about your feelings and thoughts *during the last month*. Select the number that best represents how often you felt or thought a certain way.

<table>
<thead>
<tr>
<th>Question</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>In the last month, how often have you been upset because of something that happened unexpectedly?</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>In the last month, how often have you felt that you were unable to control the important things in your life?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In the last month, how often have you felt nervous and “stressed”?</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>In the last month, how often have you felt confident about your ability to handle your personal problems?</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>In the last month, how often have you felt that things were going your way?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In the last month, how often have you found that you could not cope with all the things that you had to do?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In the last month, how often have you been able to control irritations in your life?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In the last month, how often have you felt that you were on top of things?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In the last month, how often have you been angered because of things that were outside of your control?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Profile of Mood States - Short Version**

*Primary Investigator: Penelope Larsen*
*Email: plarsen@csu.edu.au*

---

**Profile of Mood States**

*Instructions: Below is a list of words that describe feelings people have. Please select the number that best indicates how you have been feeling in the past month, including today, for each emotion.*

<table>
<thead>
<tr>
<th></th>
<th>Not At All</th>
<th>A Little</th>
<th>Moderately</th>
<th>Quite A Lot</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tense</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Angry</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Worn Out</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Unhappy</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Proud</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
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<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>Confused</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Sad</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Active</td>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
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<td>1</td>
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<td>3</td>
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<td>4</td>
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<tr>
<td>Ashamed</td>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Energetic</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Hopeless</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Uneasy</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Restless</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Unable to concentrate</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Fatigued</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<td>4</td>
</tr>
<tr>
<td>Annoyed</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Discouraged</td>
<td>0</td>
<td>1</td>
<td>2</td>
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<tr>
<td>Resentful</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Nervous</td>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Confident</td>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Better</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>Exhausted</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Anxious</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Needy</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Satisfied</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Bewildered</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Furious</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Full of Pep</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Worthless</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Forgetful</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Vigorous</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Uncertain about things</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Bushed</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Embarrassed</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

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**End of Questionnaire**

*Please turn the page for Additional information so that you can receive a report of your results*

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[www.csu.edu.au](http://www.csu.edu.au)

CRICOS Provider Numbers for Charles Sturt University are 00009F (NSW), E1147G (VIC) and 02900B (ACT). ABN: 63 876 738 531

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Appendices

Chapters Four and Five - General Practitioners Clearance Letter

Penelope Larsen
B. Ex. Sc. (Hons), PhD Candidate
School of Exercise Science, Sport & Health
Charles Sturt University
Panorama Ave, Bathurst
Tel: (02) 6338 6101
Email: phlarsen@csu.edu.au

Dear Dr. __________,

Thank you for making a consultation with ______________________ (patient’s name) regarding participation in the research study entitled “The effect of exercise mode and time-of-day on sleep quality and quantity, appetite hormones and eating behaviour”. This study will examine the effect of four (4) exercise conditions on sleep, appetite-related hormone concentration and eating behaviour among middle-aged inactive men. A requirement of the study is to perform a maximal graded exercise (VO2max) test to ensure cardiovascular fitness and perform medium to high-intensity exercise for a total of four (4) times.

The following protocol will be used to assess cardiovascular fitness on a cycle ergometer at the Exercise Physiology laboratories at Charles Sturt University, Bathurst:

- The protocol will begin at a pedal resistance of 50 watts (W) for the first two (2) minutes.
- Pedal resistance will be increased by 25 W every minute thereafter until participant reaches maximal voluntary exhaustion.
- Based on previous VO2max testing, the duration in which individuals can continue cycling is between 8 - 12 minutes. At each, participants would be cycling at an intensity between 200 - 300 W.
- Monitoring will also be conducted during VO2max testing which will include resting blood pressure and exercising ECG assessment.

There are two (2) exercise protocols which will be used for this study and each will be 30 minutes in duration:

- A continuous cycling bout (AE) requiring participants to cycle at a moderate-intensity equivalent to 60% of their VO2max for the duration of the session.
- A high-intensity interval (HIE) cycling bout requiring participants to perform 60 seconds cycling at 100% VO2peak followed by 240 seconds of active recovery at 50% VO2peak for the duration of the session.

Participants will perform one (1) AE session and three (3) HIE sessions with at least 7 days recovery between each sessions.

Could you please sign the line below to indicate that you provide medical clearance and can confirm that ______________________ (patient’s name) has the required health and fitness to complete the aforementioned study requirement. If you believe that the patient should be excluded from this study due to medical and fitness reasons, please do not sign this letter.

We thank you for your honesty.

__________________________________________
Print Name

__________________________________________
Signature

Kind Regards,

Penelope Larsen

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CRICOS Provider Numbers for Charles Sturt University are 03005F (NSW), 01470G (VIC) and 02001G (ACT). ABN: 80 676 700 551

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STOP-BANG Questionnaire

PRE-SCREENING to participate in:

‘The Effect of Exercise Mode and Time-of-Day on Sleep Quality and Quantity, Appetite Hormones and Eating Behaviour’

Please complete the below questionnaires to evaluate your risk of sleep apnoea. If your score indicates that you are at high risk of sleep apnoea and daytime sleepiness you may be excluded from this study and referred to your doctor for further medical attention.

STOP-BANG Sleep Apnoea Questionnaire

<table>
<thead>
<tr>
<th>STOP</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you SNORE loudly (louder than talking or loud enough to be heard through closed doors)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you often feel TIRED, fatigued, or sleepy during daytime?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Has anyone OBSERVED you stop breathing during your sleep?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Do you have or are you being treated for high blood PRESSURE</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BANG</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI more than 35 kg/m²?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AGE over 50 years old?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>NECK circumference &gt; 40 cm?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>GENDER: Male?</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

TOTAL SCORE: ________________

High risk of OSA: Yes 5 - 8
Intermediate risk of OSA: Yes 3 - 4
Low risk of OSA: Yes 0 - 2
Appendices

Epworth Sleepiness Scale

How Sleepy Are You?
How likely are you to doze off or fall asleep in the following situations? You should rate your chances of dozing off, not just feeling tired. Even if you have not done some of these things recently try to determine how they would have affected you. For each situation, decide whether or not you would have:

<table>
<thead>
<tr>
<th>Situation</th>
<th>No chance of dozing</th>
<th>Slight chance of dozing</th>
<th>Moderate chance of dozing</th>
<th>High chance of dozing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting and reading</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Watching TV</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Sitting inactive in a public place (e.g. cinemas or a meeting)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>As a passenger in a car for an hour without a break</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Lying down to rest in the afternoon when circumstances permit</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Sitting and talking to someone</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Sitting quietly after a lunch without alcohol</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>In a car, while stopped for a few minutes in traffic</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

**TOTAL SCORE: ____________________**

0-7: It is unlikely that you are abnormally sleepy.
8-9: You have an average amount of daytime sleepiness.
10-15: You may be excessively sleepy depending on the situation. You may want to consider seeking medical attention.
16-24: You are excessively sleepy and should consider seeking medical attention.
# Pre-Exercise Medical Health Participant Questionnaire

**Participants:** You must complete this questionnaire and obtain medical clearance from your general practitioner, if necessary, prior to your involvement in research within The School of Exercise Science, Sport & Health, Charles Sturt University, Bathurst.

**Participant's Surname:** ____________________  **First Name:** ____________________

**Address:** ____________________  

**Phone (wk):** ____________________  **AH or Mob:** ____________________  **Gender:** M / F  **DOB:** ____________________

**Emergency Contact:**
In case of emergency, please notify:

**Name:** ____________________  **Relationship:** ____________________

**Address:** ____________________  

**Phone (wk):** ____________________  **AH or Mob:** ____________________

**Risk Assessment:**
Please answer YES or NO to the following questions. Please tick √

1. Are you male over 35 years or female over 45 years and been inactive for a period of 3 months or more? □ Y □ N
2. Are you currently pregnant? □ Y □ N
3. Have you given birth within the last 6 weeks? □ Y □ N
4. Do you have any infectious or infectious diseases? □ Y □ N
5. Are you on any prescribed medication? □ Y □ N
6. Are you currently receiving any treatment from a Doctor, Physiotherapist, or any other health professional? □ Y □ N
7. Have you been hospitalised in the past 6 months? □ Y □ N

Do you have, or have you ever had any of the following? Please tick √

- Heart condition of any kind
- Cancer or tumor
- Diabetics
- Liver or kidney condition
- Epilepsy
- Nerve or muscle disease
- Stomach / Duodenal ulcer
- Asthma / bronchitis
- Shortness of breath
- Gout
- Lung disease
- HIV / AIDS
- Stroke
- Low or high blood pressure
- Hypertension
- High cholesterol / triglycerides
- Arthritis
- Diabetes
- Blood disorder
- Obstetric problems

Have you experienced any of the following in the past 6 months? Please tick √

- Allergies
- Headaches or dizziness
- Numbness in any part of the body
- Any problems with the skin
- Tendency to shake or tremble
- Problems with hearing
- Difficulties with the eye(s) or vision
- Abdominal pain
- Difficulties with nose or throat
- Ulcerated wounds or cuts

Is there any medical condition that may be exacerbated by exercise or that will place you at elevated risk of experiencing exercise-induced complications? □ Y □ N  If 'Yes', please provide details in the medical chart (Section 3).

Is there any family history of:

- High blood pressure
- Cancer or tumor
- Emotional problems
- Bowel disorder
- Other:

- Allergies / asthma
- Kidney / bladder disorder
- Epilepsy
- Problems with pregnancy
- Heart problems
- Migraine headache
- Diabetes
- Genetic disorders

Is there any family history of:

- Stomach disorders
- Arthritis
- Anaemia

**Page 280**
2. MUSCULOSKELETAL PROBLEMS:

Do you have, or have you had, any of the following? Please tick ✓
1. Injury or pain to the head, neck, ribs, cervical spine, lumbar spine, or sacroiliac joints?  ○ Y  ○ N
2. Injury or pain to shoulder(s), arm(s), elbow(s), wrist(s) or hand(s)?  ○ Y  ○ N
3. Lower back injury or pain?  ○ Y  ○ N
4. Injury or pain to hip(s), knee(s), ankle(s) or foot (feet)?  ○ Y  ○ N
5. Joint Pain?  ○ Y  ○ N
6. Tendon/ligament damage?  ○ Y  ○ N
7. Muscular pain?  ○ Y  ○ N
8. Are there any other musculoskeletal problems you are aware of that are not detailed above?  ○ Y  ○ N
9. Please identify the location of any musculoskeletal pain, injuries or symptoms on the figures below:

![Diagram of human figure with anterior and posterior views]

RIGHT  LEFT  LEFT  RIGHT

Anterior  Posterior

NOTES:

____________________________________
____________________________________
____________________________________

3. MEDICATIONS, FOOD SUPPLEMENTS, AND MISCELLANEOUS AGENTS

Please answer YES or NO to the following questions. Please tick ✓

Have you taken any prescription medications in the past 3 months?  ○ Y  ○ N

Have you ever taken any anabolic agents (eg steroids, growth hormone)?  ○ Y  ○ N

Are you currently taking any nutritional supplements (ie multi-vitamins, iron, calcium)?  ○ Y  ○ N

Have you taken any non-prescription medications not listed above?  ○ Y  ○ N

If you have answered ‘Yes’ to any of the above please provide details in the medical chart provided over the page.

Do you currently smoke?  ○ Y  ○ N  If ‘Yes’, how many cigarettes per day? ____________

Do you currently drink alcohol?  ○ Y  ○ N  If ‘Yes’, how many standard drinks per day? ____________
4. MEDICAL CHART
Please provide any details regarding YOUR medical history, including any illnesses, health problems, surgeries, or medications taken, that for safety concerns should be disclosed to your Exercise Physiologist.

<table>
<thead>
<tr>
<th>Nature of Illness, Medical Condition, or Medications</th>
<th>Dates</th>
<th>Details (e.g. duration, period of hospitalisation, name and address of GP)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. CURRENT EXERCISE HABITS

Frequency: ______ x week  Intensity: L / M / H  Time: ______ mins  Type: Cardio / Weights / Rec

It is recommended by the American College of Sports Medicine (ACSM) that all males >35 years and >45 years should have a medical assessment, including an exercise ECG, fasting blood glucose and cholesterol/lipid count, prior to undertaking an exercise program.

Declaration:

I ____________________________ (print name) recognise that the Exercise Physiologist is not able to provide me with medical advice regarding my medical condition and that this information is used as a guide to my exercise limitations. I have answered these questions accurately to the best of my knowledge and understand the recommendation by the ACSM.

Signed: ______________________  Date: ______________
Appendices

Food Cravings Questionnaire - Trait

Date: ____________
Participant ID: ____________

Food Cravings Questionnaire - Trait

Indicate with a 'X' how frequently the statements below would be true for you most times.

1. Being with someone who is eating often makes me hungry.
   Never or NA  Rarely  Sometimes  Often  Usually  Always

2. When I crave something, I know I won't be able to stop eating once I start.
   Never or NA  Rarely  Sometimes  Often  Usually  Always

3. If I eat what I am craving, I often lose control and eat too much.
   Never or NA  Rarely  Sometimes  Often  Usually  Always

4. I hate it when I give in to cravings.
   Never or NA  Rarely  Sometimes  Often  Usually  Always

5. Food cravings invariably make me think of ways to get what I want to eat.
   Never or NA  Rarely  Sometimes  Often  Usually  Always

6. I feel like I have food on my mind all the time.
   Never or NA  Rarely  Sometimes  Often  Usually  Always

7. I often feel guilty for craving certain foods.
   Never or NA  Rarely  Sometimes  Often  Usually  Always

8. I find myself preoccupied with food.
   Never or NA  Rarely  Sometimes  Often  Usually  Always

9. I eat to feel better.
   Never or NA  Rarely  Sometimes  Often  Usually  Always

10. Sometimes, eating makes things seem just perfect.
    Never or NA  Rarely  Sometimes  Often  Usually  Always

11. Thinking about my favourite foods makes my mouth water.
    Never or NA  Rarely  Sometimes  Often  Usually  Always

12. I crave foods when my stomach is empty.
    Never or NA  Rarely  Sometimes  Often  Usually  Always

13. I feel as if my body asks me for certain foods.
    Never or NA  Rarely  Sometimes  Often  Usually  Always

14. I get so hungry that my stomach seems like a bottomless pit.
    Never or NA  Rarely  Sometimes  Often  Usually  Always
15. Eating what I crave makes me feel better. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

16. When I satisfy a craving I feel less depressed. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

17. When I eat what I am craving I feel guilty about myself. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

18. Whenever I have cravings, I find myself making plans to eat. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

19. Eating calms me down. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

20. I crave foods when I feel bored, angry, or sad. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

21. I feel less anxious after I eat. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

22. If I get what I am craving I cannot stop myself from eating it. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

23. When I crave certain foods, I usually try to eat them as soon as I can. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

24. When I eat what I crave I feel great. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

25. I have no will power to resist my food crave. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

26. Once I start eating, I have trouble stopping. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

27. I can’t stop thinking about eating no matter how hard I try. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

28. I spend a lot of time thinking about whatever it is I will eat next. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always

29. If I give in to a food craving, all control is lost. 
   - Never or NA
   - Rarely
   - Sometimes
   - Often
   - Usually
   - Always
<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>30. When I’m stressed out, I crave food.</td>
<td>Never or NA</td>
<td>Rarely</td>
<td>Sometimes</td>
<td>Often</td>
<td>Usually</td>
<td>Always</td>
</tr>
<tr>
<td>31. I daydream about food.</td>
<td>Never or NA</td>
<td>Rarely</td>
<td>Sometimes</td>
<td>Often</td>
<td>Usually</td>
<td>Always</td>
</tr>
<tr>
<td>32. Whenever I have a food craving, I keep on thinking about eating until I actually eat the food.</td>
<td>Never or NA</td>
<td>Rarely</td>
<td>Sometimes</td>
<td>Often</td>
<td>Usually</td>
<td>Always</td>
</tr>
<tr>
<td>33. If I am craving something, thoughts of eating it consume me.</td>
<td>Never or NA</td>
<td>Rarely</td>
<td>Sometimes</td>
<td>Often</td>
<td>Usually</td>
<td>Always</td>
</tr>
<tr>
<td>34. My emotions often make me want to eat.</td>
<td>Never or NA</td>
<td>Rarely</td>
<td>Sometimes</td>
<td>Often</td>
<td>Usually</td>
<td>Always</td>
</tr>
<tr>
<td>35. Whenever I go to a buffet I end up eating more than what I needed.</td>
<td>Never or NA</td>
<td>Rarely</td>
<td>Sometimes</td>
<td>Often</td>
<td>Usually</td>
<td>Always</td>
</tr>
<tr>
<td>36. It is hard for me to resist the temptation to eat appetizing foods that are in my reach.</td>
<td>Never or NA</td>
<td>Rarely</td>
<td>Sometimes</td>
<td>Often</td>
<td>Usually</td>
<td>Always</td>
</tr>
<tr>
<td>37. When I am with someone who is overeating, I usually overeat too.</td>
<td>Never or NA</td>
<td>Rarely</td>
<td>Sometimes</td>
<td>Often</td>
<td>Usually</td>
<td>Always</td>
</tr>
<tr>
<td>38. When I eat food, I feel comforted.</td>
<td>Never or NA</td>
<td>Rarely</td>
<td>Sometimes</td>
<td>Often</td>
<td>Usually</td>
<td>Always</td>
</tr>
<tr>
<td>39. I crave foods when I’m upset.</td>
<td>Never or NA</td>
<td>Rarely</td>
<td>Sometimes</td>
<td>Often</td>
<td>Usually</td>
<td>Always</td>
</tr>
</tbody>
</table>
Food Cravings Questionnaire - State: Adapted to assess cravings for savoury and sweet foods

Date: ____________  Participant ID: ____________

Food Cravings Questionnaire - State
Indicate with an ‘x’ how true the following statements are for you right now, at this very moment, in relation to savoury and sweet foods.

1. I have an intense desire to eat savoury foods.
   □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

2. I have an intense desire to eat sweet foods.
   □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

3. I’m craving savoury foods.
   □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

4. I’m craving sweet foods.
   □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

5. I have an urge for savoury foods.
   □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

6. I have an urge for sweet foods.
   □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

7. Eating savoury foods would make things seem just perfect.
   □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

8. Eating sweet foods would make things seem just perfect.
   □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

9. If I were to eat what I am craving, I am sure my mood would improve.
   □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

10. Eating savoury foods would feel wonderful.
    □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

11. Eating sweet foods would feel wonderful.
    □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

12. If I ate something, I wouldn’t feel so sluggish and lethargic.
    □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

13. Satisfying my craving would make me feel less grouchy and irritable.
    □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

14. I would feel more alert if I could satisfy my craving.
    □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

15. If I had savoury foods, I could not stop eating it.
    □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree

16. If I had sweet foods, I could not stop eating it.
    □ Strongly Disagree  □ Disagree  □ Neutral  □ Agree  □ Strongly Agree
17. My desire to eat **savoury** foods seems overpowering.
   [ ] Strongly Disagree   [ ] Disagree   [ ] Neutral   [ ] Agree   [ ] Strongly Agree

18. My desire to eat **sweet** foods seems overpowering.
   [ ] Strongly Disagree   [ ] Disagree   [ ] Neutral   [ ] Agree   [ ] Strongly Agree

19. I know I’m going to keep on thinking about **savoury** foods until I actually have it.
   [ ] Strongly Disagree   [ ] Disagree   [ ] Neutral   [ ] Agree   [ ] Strongly Agree

20. I know I’m going to keep on thinking about **sweet** foods until I actually have it.
   [ ] Strongly Disagree   [ ] Disagree   [ ] Neutral   [ ] Agree   [ ] Strongly Agree

21. I am hungry.
   [ ] Strongly Disagree   [ ] Disagree   [ ] Neutral   [ ] Agree   [ ] Strongly Agree

22. If I ate right now, my stomach wouldn’t feel as empty.
   [ ] Strongly Disagree   [ ] Disagree   [ ] Neutral   [ ] Agree   [ ] Strongly Agree

23. I feel weak because of not eating
   [ ] Strongly Disagree   [ ] Disagree   [ ] Neutral   [ ] Agree   [ ] Strongly Agree
Visual Analogue Scale: Perceived Appetite

1. How hungry do you feel?
   Not hungry at all As hungry as I have ever felt

2. How full do you feel?
   Not full at all As full as I have ever felt

3. How strong is your desire to eat right now?
   Very weak Very strong

4. How much do you think you could eat right now?
   Nothing at all A large amount
## Wellness Questionnaire

**How do you feel right now?**

<table>
<thead>
<tr>
<th></th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>Record Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FATIGUE</strong></td>
<td>Very fresh</td>
<td>Fresh</td>
<td>Normal</td>
<td>More tired than normal</td>
<td>Always tired</td>
<td></td>
</tr>
<tr>
<td><strong>SLEEP QUALITY</strong></td>
<td>Very restful</td>
<td>Good</td>
<td>Difficulty falling asleep</td>
<td>Restless sleep</td>
<td>Insomnia</td>
<td></td>
</tr>
<tr>
<td><strong>GENERAL MUSCLE SORENESS</strong></td>
<td>Feeling great</td>
<td>Feeling good</td>
<td>Normal</td>
<td>Increase in soreness/tightness</td>
<td>Very sore</td>
<td></td>
</tr>
<tr>
<td><strong>STRESS LEVELS</strong></td>
<td>Very relaxed</td>
<td>Relaxed</td>
<td>Normal</td>
<td>Feeling stressed</td>
<td>Highly stressed</td>
<td></td>
</tr>
<tr>
<td><strong>MOOD</strong></td>
<td>Very positive mood</td>
<td>A generally good mood</td>
<td>Less interested in others &amp;/or activities than usual</td>
<td>Snappiness at teammates, family and friends</td>
<td>Highly annoyed/ irritable/down</td>
<td></td>
</tr>
</tbody>
</table>
Appendix C:
Supplementary Study Results
Chapter Three Supplementary Table 1 Stroop task accuracy and response time data post-sleep manipulation (post-SM) and post-exercise (post-EX) following three nights of normal sleep (CONT), sleep restriction (RES), sleep extension (EXT) and sleep fragmentation (FRAG) (Mean ± SD, n = 9).

<table>
<thead>
<tr>
<th></th>
<th>Congruent</th>
<th></th>
<th>Incongruent</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accuracy</td>
<td>Response Time (m·sec⁻¹)</td>
<td>Accuracy</td>
<td>Response Time (m·sec⁻¹)</td>
</tr>
<tr>
<td>CONT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-SM</td>
<td>5 ± 0.0</td>
<td>12.3 ± 2.8</td>
<td>15 ± 0.0</td>
<td>9.9 ± 3.3</td>
</tr>
<tr>
<td>Post-EX</td>
<td>5 ± 0.0</td>
<td>12.9 ± 3.4</td>
<td>15 ± 0.3</td>
<td>9.8 ± 3.0</td>
</tr>
<tr>
<td>RES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-SM</td>
<td>5 ± 0.0</td>
<td>12.4 ± 3.0</td>
<td>15 ± 0.3</td>
<td>12.3 ± 2.9</td>
</tr>
<tr>
<td>Post-EX</td>
<td>5 ± 0.0</td>
<td>12.3 ± 2.9</td>
<td>15 ± 0.0</td>
<td>9.7 ± 2.4</td>
</tr>
<tr>
<td>EXT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-SM</td>
<td>5 ± 0.0</td>
<td>12.5 ± 2.6</td>
<td>15 ± 0.0</td>
<td>9.5 ± 3.0</td>
</tr>
<tr>
<td>Post-EX</td>
<td>5 ± 0.0</td>
<td>11.9 ± 3.4</td>
<td>15 ± 0.7</td>
<td>9.8 ± 2.5</td>
</tr>
<tr>
<td>FRAG</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-SM</td>
<td>5 ± 0.0</td>
<td>13.7 ± 3.2 c</td>
<td>15 ± 0.0</td>
<td>10.0 ± 1.8</td>
</tr>
<tr>
<td>Post-EX</td>
<td>5 ± 0.3</td>
<td>12.5 ± 4.2</td>
<td>15 ± 0.7</td>
<td>9.9 ± 2.3</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD.

c Indicates significant difference between CONT and FRAG (p ≤ 0.03).