Sleep And Physical Activity: A Mixed Method Study In People With Chronic Pain

By

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List Of Abbreviations

AEM	:	Avoidance-Endurance Model
AIC	:	Akiake Information Criterion
AOR	:	Adjusted Odds Ratio
BIC	:	Bayesian Information Criterion
BMI	:	Body Mass Index
BPI	:	Brief Pain Inventory
CBT	:	Cognitive Behaviour Therapy
CBT-I	:	Cognitive Behaviour Therapy for Insomnia
COREQ	:	Consolidated Criteria for Reporting Qualitative Research
CPM	:	Conditioned Pain Modulation
CPT	:	Cold Pressor Task
CSD	:	Consensus Sleep Diary
DBAS-16	:	Dysfunctional Beliefs and Attitude about Sleep-16
DSM-5	:	Diagnostic and Statistical Manual of Mental Disorders, 5th Edition
EEG	:	Electroencephalography
EMG	:	Electromyography
EOG	:	Electrooculography
ESS	:	Epworth Sleepiness Scale
FAM	:	Fear-Avoidance Model
HADS	:	Hospital Anxiety and Depression Scale
IASP	:	International Association for the Study of Pain
ICSD-3	:	International Classification of Sleep Disorders-3
ISI	:	Insomnia Severity Index
MCMC	:	Markov Chain Monte Carlo
MCMCP	:	Markov Chain Monte Carlo with People
MEQ	:	Morningness-Eveningness Questionnaire
MFI	:	Multidimensional Fatigue Inventory
OR	:	Odds Ratio
PAMSys	:	Physical Activity Monitoring System
PBAS	:	Pain-Related Beliefs and Attitudes about Sleep
POAM-P	:	Patterns of Activity Measure-Pain
PSG	:	Polysomnography

PSQI	:	Pittsburgh Sleep Quality Index
QALY	:	Quality-Adjusted Life-Year
RCT	:	Randomised Controlled Trial
REM	:	Rapid Eye Movement
SE	:	Sleep Efficiency
SOL	:	Sleep Onset Latency
SWS	:	Slow Wave Sleep
TIB	:	Time In Bed
TST	:	Total Sleep Time
TSK-11	:	Tampa Scale for Kinesophobia-11
WAKE	:	Number of Wake After Sleep Onset
WASO	:	Wake After Sleep Onset
WHO	:	World Health Organization

Dedication

In the fond memory of my late father *Ramlee Ismail*, whose wisdom and passion for knowledge has always inspired me

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Declaration

This thesis is submitted to the University of Warwick in support of my application for the degree of Doctor of Philosophy in Psychology. It has been composed by myself and has not been submitted in any previous application for any degree. The work presented (including data generated and data analysis) was carried out entirely by the author.

Inclusion of Published Work

Part of this thesis has been published by the author:

Chapter 3 includes the following publication:

Ramlee, F., Afolalu, E. F., & Tang, N. K. Y. (2016). Do people with chronic pain judge their sleep differently? A qualitative study. *Behavioral Sleep Medicine*, 1-16.

Dr. Nicole Tang contributed to the planning and supervision of this research. All co-authors provided feedback on drafts of the manuscript.

Chapter 4 includes the following publication:

Ramlee, F., Sanborn, A. N., & Tang, N. K. Y. (2017). What sways people's judgement of sleep quality? A quantitative choice-making study with good and poor sleepers. *Sleep,* 40(7).

Dr. Nicole Tang contributed to the planning and supervision of this research. Dr. Adam Sanborn contributed to the planning, analysis and supervision of this research. All co-authors provided feedback on drafts of the manuscript.

Outputs Arising From This Thesis

Publications

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Poster Presentations

Ramlee, F., & Tang, N. K. Y. (2017, May). *Does a good night's sleep contribute to improving daytime physical activity? A daily process study in patients with chronic pain*. Poster presented at the British Pain Society's 50th Anniversary Annual Scientific Meeting, Birmingham, United Kingdom.

Ramlee, F., Sanborn, A. N., & Tang, N. K. Y. (2015, November). *What is a poor night's sleep? A quantitative approach to unravel the meaning of sleep quality*. Poster presented at the 7th World Congress of the World Sleep Federation (WSF 2015), Istanbul, Turkey.

Ramlee, F., Afolalu, E. F., & Tang, N. K. Y. (2015, September). *Do people with chronic pain judge their sleep differently? A qualitative study*. Poster presented at the 9th Congress of the European Pain Federation (EFIC 2015), Vienna, Austria.*****

******Award:* **The Best Poster Presentation on the Subject of Clinical Science**

Ramlee, F. & Tang, N. K. Y. (2014, June). *Exploring the essential ingredients of a good night's sleep: A qualitative study with people with fibromyalgia, back pain and healthy individuals without chronic pain.* Poster presented at Research Postgraduate Poster Showcase, University of Warwick, Coventry.

Ramlee, F. & Tang, N. K. Y. (2014, May). *Exploring the essential ingredients of a good night's sleep: A qualitative study with people with fibromyalgia, back pain and healthy individuals without chronic pain*. Poster presented at Psychology Postgraduate Research Day, University of Warwick, Coventry.

Oral Presentations

Ramlee, F., Sanborn, A. N., & Tang, N. K. Y. (2016, May). *What is a poor night's sleep? A quantitative choice making approach to unravel the parameters of sleep quality*. Oral presentation at Psychology Postgraduate Research Day (PGR 2016), University of Warwick, Coventry.

Ramlee, F. & Tang, N. K. Y. (2015, September). Sleep and daytime physical activity in people with chronic pain. Oral presentation at Rheumatology Department, University Hospital Coventry and Warwickshire, Coventry.

Additional Research Conducted With Warwick Sleep And Pain Laboratory

Publications

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Afolalu, E. F., Moore, C., **Ramlee, F.**, Goodchild, C. & Tang, N. K. Y. (2016). Development of the Pain-Related Beliefs and Attitudes about Sleep (PBAS) scale for the assessment and treatment of insomnia comorbid with chronic pain. *Journal of Clinical Sleep Medicine*, 12(9), 1269-1277.

Book Chapter

Tang, N. K. Y., Afolalu, E. F., & **Ramlee, F.** (2018). Sleep and Pain. In F. P. Cappuccio, M. A. Miller, & S. W. Lockley (Eds.) *Sleep Health and Society – From Aetiology to Public Health*, 2nd Edition. Oxford, U.K.: Oxford University Press.

Poster Presentations

Afolalu, E. F., **Ramlee, F.**, & Tang, N. K. Y. (2017, May). *Reliability of conditioned pain modulation in a healthy population: investigating the influence of distraction, pain catastrophising and sleep.* Poster presented at the British Pain Society's 50th Anniversary Annual Scientific Meeting, Birmingham, United Kingdom.*****

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Abstract

This thesis investigates how people make judgements of their sleep quality and the temporal association between sleep and physical activity in people with and without chronic pain. In doing so, the thesis used a multi-methodological approach comprising qualitative (Chapter 3), experimental (Chapter 4) and daily process studies (Chapters 5 and 6). The qualitative study presented in Chapter 3 explored how people with and without chronic pain define their sleep quality and to what extent judgments of sleep quality differ with the presence of pain (*n*= 17). The experimental study presented in Chapter 4 quantitatively examined the relative importance of 17 parameters of sleep quality in good and poor sleepers (*n*= 100). This study conceptualised sleep quality as a decision-making process and used a choice-based conjoint analysis to identify parameters that shape people's judgement of sleep quality. Then the thesis shifts its focus to the relationship between sleep and physical activity in Chapters 5 and 6. Using self-reported measures, the daily process study presented in Chapter 5 investigated the temporal within-person association between sleep and physical activity in healthy young adults (*n*= 118). Using both self-reported and objective measures of sleep and physical activity, a follow-up daily process study was conducted in people with chronic pain (*n*= 51, Chapter 6). In addition, the study presented in Chapter 6 also explored the roles of pain and other psychological variables (e.g., mood) that may interact with sleep to affect the regulation of physical activity. The results across studies converge to suggest that sleep quality judgement is a retrospective decision-making process dependent on both daytime and nighttime processes and that subsequently influence daytime functioning such as physical activity and mood in chronic pain patients. Therefore, future investigations and interventions should consider the possibility of broadening the focus to addressing chronic pain patient's perception of sleep quality and the impact of poor sleep on daytime processes, for improving sleep quality, engagement in physical activity and the overall quality of life.

Chapter 1

General Introduction

1.1 The beginning of the research programme

Six years ago, I had the opportunity to carry out a research project for my Master's study at a haemodialysis centre. I found out that sleep was an important issue to patients undergoing haemodialysis. Although at that time, I did not have much knowledge about sleep, the experience of working with these patients has inspired me to explore sleep problems in people living with chronic medical conditions as part of my doctoral research. At Warwick, I was given the opportunity to study sleep in chronic pain and this thesis presents the work I have done here.

1.2 Prevalence of chronic pain, sleep disturbance and reduced physical activity

The prevalence of sleep disturbance is very high among people with chronic pain. Chronic pain is defined as pain that persists for more than three to six months, beyond the expected time of healing (IASP Task Force on Taxanomy, 1994; Treede et al., 2015). Chronic pain is a debilitating health condition and a major health problem worldwide. The prevalence of chronic pain for adults (≥18 years old) was 30.7% in the United States (Johannes, Le, Zhou, Johnston, & Dworkin, 2010) and 18.9% in Canada (Schopflocher, Taenzer, & Jovey, 2011). In the United Kingdom (UK), the estimated prevalence of chronic pain (lasting more than three months) is 43% (Fayaz, Croft, Langford, Donaldson, & Jones, 2016). A large-scale survey involving 46,394 adults in 15 European countries and Israel indicates that 19% of the respondents have chronic pain that significantly affects their quality of life (Breivik, Collett, Ventafridda, Cohen, & Gallacher, 2006). Based on Breivik et al.'s survey (2006), individuals suffering from chronic pain indicated that they were no longer able or less able to work outside home (61%), lift (72%), exercise (73%), drive (47%), have sexual relations (43%), attend social activities (48%), carry out household chores (54%), sleep (65%), walk (47%), maintain an independent lifestyle (30%) and maintain relationships with family and friends (27%). Importantly, pain was the top cause of quality-adjusted life-year (QALY)[1] losses in primary health care, above mood disorder and anxiety as well as other chronic physical conditions such as cardiovascular disease and diabetes (Fernández et al., 2010).

At the societal level, chronic pain has an impact on economy. Pain has been cited as a primary reason of missed work (U.S. Department of Health and Human Services, 2017). Consequently, it causes an economic loss specifically in term of loss of productive working time in the workforce (Stewart, Ricci, Chee, Morganstein, & Lipton, 2003). Besides, in the UK, 25% of individuals with chronic pain lost their job as a result of pain (Breivik et al., 2006; Breivik, Eisenberg, & O'Brien, 2013). At the individual level, the impact of chronic pain is more devastating. The reported statistics are grim as chronic pain has a negative impact on daily activities, employment, psychological, physical and social functioning (Smith & Osborn, 2007; Widerstrom-Noga, Felipe-Cuervo, & Yezierski, 2001).

A number of surveys have also shown that sleep impairment is a common comorbidity of chronic pain. In a survey of five European countries (i.e., UK, Germany,

[1] QALY takes into account both quantity and quality of life. It is an indicator of life expectancy weighted by the quality of the remaining life years (Fernandez et al., 2010). For example, a year of life lived in perfect health is worth 1 QALY, half a year lived in perfect health is equivalent to 0.5 QALY and death is equivalent to 0.

Italy, Portugal and Spain), 23% of individuals with chronic painful physical condition reported at least one insomnia symptom in comparison to only 7.4% among individuals without chronic pain (Ohayon, 2005). A recent large-scale population-based study involving 6,205 older adults (≥65 years of age) in Sweden found that older adults with chronic pain had a high proportion of clinical insomnia (24.6%) compared to older adults with subacute pain (21.3%) and without pain (13%) (Dragioti, Levin, Bernfort, Larsson, & Gerdle, 2017). The prevalence of chronic pain comorbid with sleep disturbance in clinical populations is also high. Approximately 50-80% of patients with chronic pain seeking treatment at the pain clinics reported to have clinical insomnia (Mccracken, Williams, & Tang, 2011; Tang, Wright, & Salkovskis, 2007).

Insomnia refers to difficulty initiating sleep, difficulty maintaining sleep and/or early morning awakenings with inability to return to sleep and those difficulties occur despite adequate opportunity for sleep (The Diagnostic and Statistical Manual of Mental Disorders 5th Edition (DSM-5), American Psychiatric Association, 2013). Insomnia is predominantly a complaint of dissatisfaction with sleep quantity or quality causing significant distress in social, occupational or other areas of functioning such as cognition, mood, fatigue and daytime sleepiness (American Psychiatric Association, 2013; Fortier-Brochu, Beaulieu-Bonneau, Ivers, & Morin, 2012; Kyle, Morgan, & Espie, 2010; Ustinov et al., 2010). Ustinov et al. (2010) found that a report of insomnia was a significant predictor of poor daytime functioning in 734 adults with (*n*=235, mean age= 59 years) and without insomnia (*n*= 499, mean age= 51.3 years). Ustinov et al. (2010) included two types of participants in the study, which were those who reported a sleep problem (i.e., trouble falling asleep or staying asleep) lasting at least 6 months and those who reported no sleep problem. Fortier-Brochu et al. (2012) carried out a meta-analysis to examine the magnitude differences in daytime cognitive functioning between individuals with primary insomnia and normal sleepers. Findings revealed that there were significant impairments of small to moderate magnitude in some aspects of daytime cognitive functions (i.e., episodic memory, problem solving, working memory) among individuals with primary insomnia compared to normal sleepers. Kyle et al. (2010) also reported that insomnia has a negative impact on various aspects of health-related quality of life (HRQoL). These aspects include vitality, energy, mental, social and physical functioning.

Insomnia is associated with significant economic and societal burden (Daley, Morin, LeBlanc, Grégoire, & Savard, 2009; Godet-Cayré et al., 2006; Ozminkowski, Wang, & Walsh, 2007). In the workplace, at least 50% of individuals with insomnia have one work absence compared to only 34% of good sleepers (Godet-Cayré et al., 2006). Findings from a retrospective cohort study in France showed that the mean extra cost of insomnia-related work absenteeism of the national health insurance system was € 77 per employee, per year (Godet-Cayré et al., 2006). The employer bore an extra cost of €233 for salary replacement and €1062 for loss of productivity. In the US, the direct costs of untreated insomnia (estimated from the medical claims data) for individuals with insomnia were approximately $1,143 higher than individuals without insomnia (Ozminkowski et al., 2007).

Reduced physical activity is a common consequence of chronic pain with more than 40% of individuals suffering from chronic pain being less able to exercise, walk and do household chores (Breivik et al., 2006). Studies have also indicated that people with chronic pain are generally less physically active than those without chronic pain (Griffin, Harmon, & Kennedy, 2012; Kop et al., 2005; McBeth, Nicholl, Cordingley, Davies, & MacFarlane, 2010; McLoughlin, Colbert, Stegner, & Cook, 2011; Ryan et al., 2009; van den Berg-Emons, Schasfoort, de Vos, Bussmann, & Stam, 2007; Verbunt et al., 2003). Griffin et al. (2012) conducted a systematic review to examine differences in the physical activity pattern between patients with chronic low back pain and healthy individuals. The systematic review used the electronic databases from the start of each database until the end of December 2009 (i.e., Embase, Medline, ISI Web of Knowledge, Cinahl, Sport Discus and Nursing and Allied Health). Of 1414 potentials citations retrieved, seven studies were included in the final review comprising four studies among adults aged 18-65 years, two studies among older adults aged ≥65 years and one study among adolescents aged <18 years. These studies used different physical activity measures, which ranged from self-report and activity monitoring to the use of pedometers. Griffin et al. (2012) found that patients with chronic low back pain showed an altered pattern of physical activity over the course of a day than healthy controls. Patients with chronic low back pain were significantly less active in the evening compared to healthy controls.

Other individual studies using accelerometer and clinical population also found that patients with chronic pain were physically less active than pain-free individuals (e.g., Kop et al., 2005; van den Berg-Emons et al., 2007). van den Berg-Emons et al. (2007) compared activity level of patients with chronic pain (*n*= 18) with healthy individuals (*n*= 18) using an accelerometer. They found that patients with chronic pain exhibited lower overall levels of physical activity compared to the healthy control group. Kop et al. (2005) monitored activity levels of patients with fibromyalgia and/or chronic fatigue syndrome (*n*= 38) and age-matched healthy controls (*n*= 27) using actigraph accelerometer for 5 days. Activity levels comprised a cumulative count of activity units for every 5-minute period. Patients with fibromyalgia and/or chronic fatigue syndrome (mean= 8654 units) demonstrated lower peak activity levels than individuals in the control group (mean= 12913 units). Patients with fibromyalgia and/or fatigue syndrome also spent less time in high-level activities than individuals in the control group. Previous correlational studies in older adults have also shown that sleep disturbance is associated with physical activity such as walking speed, completion of sit-to-stand tasks and activities of daily living (Dam et al., 2008; Goldman et al., 2007).

Taken together, sleep and physical activity are the top concerns of people living with chronic pain. Specifically the survey from Brevik et al.'s (2006) study showed that more than half of people with chronic pain were "no longer able to" and "less able to" exercise, sleep or walk. However, despite the high prevalence of sleep disturbance and reduced physical activity in chronic pain, little is understood about the complex relationship between sleep and physical activity. Therefore, the overarching aim of this thesis is to investigate sleep quality and the pathway through which sleep influences engagement in daytime physical activity. Two different but complementary research approaches were employed. The two approaches were qualitative and quantitative (i.e., experimental and daily process studies). A qualitative approach provides in-depth exploration of sleep experience and insights from participants' perspective. Meanwhile, a quantitative approach uses a more rigorous statistical method and larger sample sizes to examine the relationship between sleep and physical activity. These two approaches provide a holistic picture to fill a gap in the literature and meet the aims of the research programme.

1.3 Aims of the research programme

The overarching aim of this research programme is to investigate sleep quality and the pathway through which sleep influences engagement in physical activity. The first two studies presented in the thesis focus on exploring and refining the concept of sleep quality (Aims 1 and 2), whilst the next two studies focus on investigating the link between sleep and physical activity, as well as the possible roles of pain and other psychological variables (Aims 3 and 4).

1) To explore and compare the definition of sleep quality in people with and without chronic pain and to examine to what extent judgments of sleep quality differ with the presence of pain (See Chapter 3).
2) To quantitatively examine the relative importance of 17 parameters of sleep quality in good and poor sleepers (See Chapter 4).
3) To examine the temporal association between sleep and next day physical activity, and the temporal association between daytime physical activity and

subsequent sleep on a day-to-day basis in healthy young adults (See Chapter 5) and patients with chronic pain (See Chapter 6).

4) To investigate the possible role of the psychological variables in determining subsequent physical activity. These psychological variables were pain, mood, tiredness, sleepiness, energy level, body condition, motivation to accomplish tasks, confidence to get things done and management of pain right now and later (See Chapter 6).

1.4 Overview of the thesis

Chapter 2 presents a brief introduction to sleep and physical activity in the context of chronic pain. Specifically, this chapter provides a background on sleep, its functions and the physiological processes regulating sleep. This chapter also provides a brief background on assessment of sleep and physical activity ranging from self-reported measures to objective measures. Besides, this chapter discusses the nature of sleep disturbance in chronic pain and the relationship between pain and sleep. Next, this chapter focuses on physical activity and its relationship with sleep, the theoretical models of physical activity in people with chronic pain and, finally, this chapter provides a brief discussion on the possible roles of psychological variables in predicting physical activity.

Chapter 3 presents a qualitative study that explored the definition of sleep quality in people with and without a pain condition (Ramlee, Afolalu, & Tang, 2016). Apart from Harvey, Stinson, Whitaker, Moskovitz, and Virk (2008) and Kleinman et al.

(2013), there is a lack of research that explores the subjective meaning of sleep quality specifically in chronic pain population. The aim of this qualitative study was to offer an in-depth exploration of participants' mental representation of sleep quality using their own words (Pope & Mays, 1995). A thematic analysis was carried out on all interview transcripts to uncover potential factors that determine people's judgment of sleep quality (Braun & Clarke, 2006). Although the thematic analysis has the flexibility to generate unexpected insight from the data, interpretation of the data may have been influenced by personal beliefs and biases. Therefore, several measures were also taken to minimise the biases. These are also described in detail in Chapter 3.

Chapter 4 complements Chapter 3 by quantitatively investigating the relative importance of parameters of sleep quality cited by good and poor sleepers (Ramlee, Sanborn, & Tang, 2017). The quantitative approach complements the qualitative approach by allowing the data to be extracted from a larger sample under a controlled condition and analysed using a rigorous statistical method. In this experiment, sleep quality judgment was conceptualised as decision-making process. Using a choice-based conjoint analysis, participants were presented with a series of choices between options with different sleep quality parameters. Two sleep/wake scenarios encompassing possible sleep quality parameters that occur at different times of the day (i.e., day before, pre-sleep, during sleep, upon waking, day after) were presented to the participants. Participants were asked to choose one of the two scenarios and went through 48 trials. The advantage of this approach over other methods (e.g., qualitative) is being able to present all possible sleep quality parameters simultaneously and each parameter was anchored to different options. Besides, this study can quantitatively examine the relative importance of these possible parameters as well as interactions with each other by using logistic regression. Together, both Chapters 3 and 4 will present multiple parameters of sleep quality and by clarifying what people mean when they explicitly said they have had a good (or poor) night's sleep has provided insight into people's judgment of their sleep experience. Having defined what is meant by sleep quality, the thesis shifts its focus to the link between sleep and physical activity in Chapters 5 and 6.

Chapter 5 presents a daily process study that was conducted in healthy young adults. The daily process study involved repeated monitoring of sleep and physical activity over certain period (i.e., 7 days in the present study) (Affleck, Urrows, Tennen, Higgins, & Abeles, 1996). Using self-reported measures of sleep and physical activity, this daily process study provided a preliminary examination of the relationship between sleep and physical activity in the participants' natural living and sleeping environment. This study recruited healthy young adults to minimise the influence of medical symptoms and use of medications on day-to-day sleep and physical activity. The advantage of this method is that it allowed an examination of temporal association between sleep and physical activity and an analysis of the within-person association on day-to-day basis. The data collected were time-specific in nature because participants were required to complete sleep diary in the morning and the physical activity diary at bedtime. Therefore, the data can be used to examine the temporal effect of sleep on next day physical activity and the effect of physical activity on the subsequent sleep.

Chapter 6 presents a follow-up daily process study that was conducted in people with chronic pain. Using both self-reported and objective measures of sleep and physical activity, the study adapted and extended the methods established in Chapter 5 to examine the bidirectional relationship between sleep and physical activity in the chronic pain patients' natural living and sleeping environment. In addition, Chapter 6 also investigated the possible roles of pain and other psychological variables that may interact with sleep to affect the regulation of daytime physical activity.

Chapter 7 presents the general discussion and conclusions that may be drawn from the studies presented in this thesis. The chapter begins with summary of the key findings, followed by discussion of overall findings, overall limitations of the research, and importantly implications and future directions.

Chapter 2

Background Of Sleep And Physical Activity In The Context Of Chronic Pain

This chapter aims to set a background for the thesis by providing a brief introduction to sleep and physical activity in the context of chronic pain. It starts with introducing sleep, its function and the physiological processes involved in the regulation of sleep. This chapter also introduces the technology used for assessing sleep, ranging from both self-reported to objective methods. Chapter 1 has shown that sleep disturbances and physical inactivity are major concerns in people with chronic pain, hence this chapter will go into the details of the nature of the sleep disturbances experienced by people with chronic pain. Several insomnia models that explain the development and maintenance of insomnia and evidence of the relationship between sleep and pain is then reviewed. Having discussed how sleep and pain are related, the next sections of this chapter highlight physical activity and health outcomes, assessment of physical activity and the relationship between sleep and physical activity. Finally, this chapter provides an overview of the theoretical models of physical activity in people with chronic pain and possible roles of pain and psychological variables in predicting physical activity.

2.1 Sleep and its function

Sleep can be defined as "*a reversible behavioural state of low attention to the environment typically accompanied by a relaxed posture and minimal movement*"

(Moorcroft, 2013, p. 24). The typical indicators of sleep are postural recumbence, behavioural quiescence and closed eyes (Carskadon & Dement, 2011). When people are asleep, they are less aware of their surroundings, exhibit reduced activity and reduced responsiveness to external stimuli. Wyatt, Bootzin, Anthony and Bazant (1994) found that participants who slept for 10 minutes exhibited severe deficit in free recall for words presented to them three minutes before sleep onset. The authors highlighted retrograde and anterograde amnesia during the early stage of sleep process.

Sleep is an active process that involves changes in brain activity, physiological functions and regulation of various bodily systems. Some of the possible functions of sleep include body restoration, tissue restoration and growth, toxins removal, energy conservation, consolidation of memory and learning, and emotional regulation (Adam & Oswald, 1984; Harrison, 2012; Siegel, 2001). The possible functions of sleep can be observed through the “removal of sleep”. The negative effects would appear when sleep is being taken away (e.g., when people go on without sleep or when people experience sleep deprivation). For example a classic case study in the 1960s, Randy Gardner a high school student in San Diego stayed awake without sleep for 264 continuous hours to break the world record. Towards the end of the experiment, he started showing episodes of fragmented thinking, tiredness, mood changes, irritability, inability to complete a task, paranoia and hallucination. All the symptoms emerged within just a few days (Moorcroft, 2013).

Rechtschaffen, Bergmann, Everson, Kushida, and Gilliland (1989) summarised results of a series of studies on sleep deprivation in rats. Using disk-over-water method, an experimental rat and a control rat were placed on two sides of a divided horizontal disk (rotating platform). The disk was automatically rotated whenever the experimental rat began to sleep or entered a "forbidden" sleep stage. The rotated disk awakened the experimental rat and forced both experimental and control rats to move opposite to disk rotation to avoid the water. Hence, both rats had the same physical stimulation. The stimulation was also scheduled to awake the experimental rat. The findings (Rechtschaffen & Bergmann, 2002; Rechtschaffen et al., 1989) showed that rats could survive between 11 to 32 days after total sleep deprivation (TSD) and survive between 16 to 54 days after chronic paradoxical sleep deprivation (PSD). The rats also had a scrawny and debilitated appearance with brownish and dishevelled fur as well as severe ulcerative and hyperkeratotic skin lesions in their tails and paws. Despite increased food intake, the rats also showed weight loss. The rats exhibited an increase in energy expenditure and plasma norepinephrine (i.e., responsible for stress, aging and reducing survival). In addition, the rats showed a decrease in body temperature and plasma thyroxine (i.e., responsible for regulating the metabolism). Taken together, these findings revealed important functions of sleep.

More recent experiments have shown that sleep may serve as housekeeping functions. Experiment in mouse motor cortex showed that sleep promotes the formation of postsynaptic dendritic spines on specific branches of individual layer *V pyramidal neurons* after motor learning (Yang et al., 2014). This motor learning increased the formation rate of new dendritic spines over the course of 6 to 48 hours. Although multiple motor tasks are learned, the dendritic spines are protected from being eliminated. Yang et al.'s (2014) findings highlight a key role of sleep in learning and memory formation. Experiments using mice also demonstrated that sleep serves an important function in the metabolic homeostasis. Using in vivo two-photon imaging, Xie et al. (2013) compared the cerebrospinal fluid in the cortex of awake, anesthesised, and sleeping mice. They found that the natural sleep is associated with a 60% increase in the interstitial space that surrounds cells of the brain. The convective fluxes of interstitial fluid increased the rate of β-amyloid (i.e., protein associated with neurodegenerative disease) clearance. Therefore, it is possible that the restorative sleep was a result of the removal of neurotoxic waste products accumulated in the central nervous system (Xie et al., 2013). Walker and van der Helm's (2009) experiment showed that 38 hours of sleep deprivation alters emotional memory encoding. Using a combination of positive, negative and neutral words as stimuli, the authors found that there was 40% reduction in the ability to form new memories among participants who were sleep deprived compared to the participants who had slept normally. However when the authors separated the emotional stimuli into three types (i.e., positive, negative and neutral words), the findings showed the magnitude of encoding impairment differed. Participants who were sleep deprived demonstrated 59% retention deficit for neutral and positive words compared to the participants who had slept normally. These results show that sleep plays a role in the formation of emotional memories.

2.2 Sleep regulation processes: The two-process model

The two-process model is one of the prominent models of sleep regulation. The two-process model describes the processes that regulate sleep and wakefulness. It explains the interaction between Process S (sleep-dependent process), which represents homeostatic sleep drive and Process C (sleep-independent circadian process), which represents circadian process (Achermann, 2004; Borbely, 1982). According to the model, Process S regulates sleep tendency as it builds up the intensity of homeostatic sleep drive while the individual is awake and decreases during sleep. Process S is dependent upon the amount of wakefulness and sleep. Meanwhile Process C refers to the circadian process that keeps track of the environmental time of sleep periods and wakefulness. The interaction between Process S and C maintain sleep during the night and wakefulness during the day. Figure 2.1 describes the interaction between these two processes in determining the timing and duration of sleep. When Process C (see Figure 2.1) approaches the "sleep gate", this would trigger sleep. In contrast, when Process S approaches the lower boundary of the curve, this would trigger awakening. According to Borbely and Achermann (1999), the principal marker of S during sleep is represented by the slow wave activity during the non-rapid eye-movement (NREM) and during waking is represented by the theta activity. Meanwhile, the markers for C are core body temperature and melatonin rhythms. The light-sensitive pacemaker in the suprachiasmatic nuclei produces melatonin (Dijk, Shanahan, Duffy, Ronda, & Czeisler, 1997). In addition, both Process S and C can be influenced by surroundings such as daylight exposure, loud noise and bodily activity (Moorcroft, 2013).

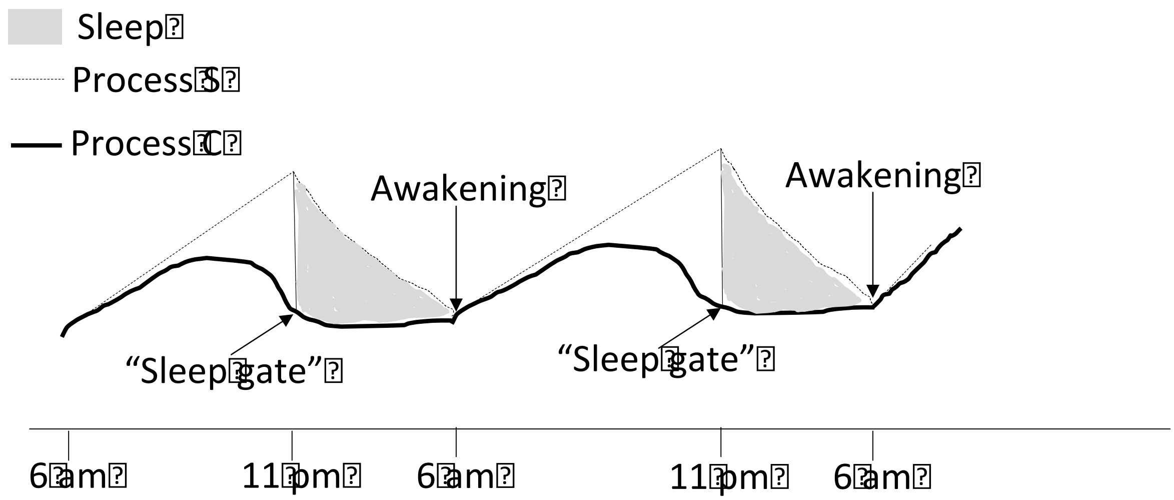

Figure 2.1 The two-process model (Adapted from Borbely, 1982)

2.3 Measures of sleep

Sleep is a private experience for everyone. The state of sleep can be assessed using objective and self-reported measures. Some examples of objective measures are polysomnography (PSG) and actigraphy. Meanwhile examples of self-reported measures are sleep diary and questionnaires.

Polysomnography is the "gold standard" physiological measure of sleep. PSG records brain activity (electroencephalography- EEG), eye movement (electrooculography- EOG) and muscle tone (electromyography- EMG) during sleep (American Association of Sleep Technologists, 2012; Morin & Espie, 2004; Moorcroft, 2013). Sleep starts with alert wakefulness, drowsy wakefulness and then followed by different stages of sleep; N1, N2, N3 sleep and rapid eye movement sleep (REM). N1, N2 and N3 are also referred as non-REM sleep. N1 and N2 are light sleep and N3 is a deep sleep/ slow wave sleep (SWS). It is called SWS because typical EEG output shows slower-frequency delta waves. PSG is usually carried out in the sleep laboratory under the supervision of a trained sleep researcher or sleep technologist. PSG has the advantage of providing more fine-grained and precise information of sleep architecture. For example, it provides more information about the total time of each sleep stage and the transition from one sleep stage to another. The main limitations of PSG, however, are that it is expensive and requires a trained sleep technologist/ researcher to set up, analyse and interpret the PSG data (American Association of Sleep Technologists, 2012). The PSG study is usually conducted in the sleep laboratory for a short duration (e.g., two nights). Thus, actigraphy will be a viable sleep measurement with greater ecological validity.

Actigraphy involves the use of an actigraph equipped with a piezo-electric accelerometer to record physical movement/ motion and is usually placed on the wrist (or ankle). The sleep-wake patterns are estimated from periods of activity and inactivity as it works based on the assumption that “people make more movement during wake and less movements during sleep” (American Association of Sleep Technologist, 2012; Ancoli-Israel et al., 2003). Examples of sleep parameters that could be derived from actigraphy are bedtime, get up time and sleep efficiency. The advantages of actigraphy as a measure that it is lightweight, non-intrusive and can continuously record sleep-wake activity for longer periods. However, actigraphy is less sensitive to detect the precise moment of sleep onset specifically in people who lie in bed motionless for long periods (Ancoli-Israel et al., 2003). This motionless period maybe interpreted as sleep when in fact it is still awake. Therefore, actigraphy should always be used with a sleep diary. Sleep diary can be used to estimate bed times and get up times.

Sleep diary is a self-report instrument designed to record the individual’s sleep experience (Carney et al., 2012). It usually consists of questions pertaining to bedtime, get up time, sleep duration, sleep onset latency (i.e., how long did it take one to fall asleep), number of times awakening from sleep, duration of awakenings, and sleep quality rating. People complete the sleep diary every morning as soon as they wake up based on their previous night’s sleep. A sleep diary has the advantage of being a practical way of data collection on sleep/ wake patterns by gathering information from individual’s own estimations of sleep experience. However, sleep diary has a number of limitations since it is self-report in nature. Sleep diary is subject to recall and reporting biases. Sleep diary is also a burden to the participants, as they need to complete sleep diary every morning. Potentially missing data would occur as a result of incomplete sleep diary.

Questionnaires are used to provide a means for people to report their sleep experience. The commonly used sleep questionnaires include the Pittsburgh Sleep Quality Index (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989), Insomnia Severity Index (Bastien, Vallières, & Morin, 2001) and Jenkins Sleep Questionnaires (Jenkins, Stanton, Niemcryk, & Rose, 1988). These questionnaires have the advantage of being cost-effective and easy to administer. In addition, most of these questionnaires have established reliability and validity. However, a problem with the use of these questionnaires was biases. Since, the questionnaires depend on self-report and are retrospective (e.g., over weeks or months), the data from questionnaires are limited to recall and reporting biases.

Actigraphy, sleep diary and questionnaires were used to measure sleep for considerations of the aims of the studies and the intention to assess sleep in the participants' natural living and sleeping environment in Chapters 5 and 6.

2.4 Nature of the sleep disturbance in chronic pain

As discussed in Chapter 1, sleep disturbance is one of the highest prevalence of complaints in people with chronic pain. Findings show that patients with chronic pain exhibited poor and fragmented sleep. They reported longer sleep onset latency (i.e., more than an hour), more frequent awakenings (i.e., 3 to 4 times) after sleep onset that often last more than an hour and shorter total sleep time of less than five hours (Menefee et al., 2000; Morin, Gibson, & Wade, 1998; Tang, Goodchild, Hester, & Salkovskis, 2012). Besides, they have low actigraphic sleep efficiency (O'Donoghue, Fox, Heneghan, & Hurley, 2009) and mostly have difficulties initiating and maintaining sleep (i.e., longer sleep onset latency and more awakenings after sleep onset) in comparison to good sleepers (Morin et al., 1998a). Studies have also shown that people with chronic pain experience disrupted sleep architecture at both macro and micro EEG levels. At the macro EEG level, patients with chronic pain exhibited more frequent awakenings, greater stage shifts, increased N1 and N2 and decreased N3 (Blagestad et al., 2012; Kishi et al., 2011; Landis, Lentz, Rothermel, Buchwald, & Shaver, 2004; Landis, Lentz, Tsuji, Buchwald, & Shaver, 2004; Rizzi et al., 2004; Roizenblatt, Moldofsky, Benedito-Silva, & Tufik, 2001). At the micro EEG level, findings revealed that there was reduced spindle activity during N2 sleep in chronic low back pain and fibromyalgia (Harman et al., 2002; Landis et al., 2004). Landis et al. (2004) conducted a PSG study to investigate sleep spindles and spindle activity in patients with fibromyalgia (*n*= 37) and pain-free and good sleeper individuals (*n*= 30). Patients with fibromyalgia exhibited fewer sleep spindles (i.e., 5) and reduced spindle activity during N2 sleep compared to the pain-free, good sleeping control group (Landis et al., 2004). These sleep spindles and spindle activity might disturb sleep initiation and maintenance processes as there were impairments in the thalamocortical mechanisms.

A number of studies have also found that there was an intrusion of alpha EEG activity during N3 sleep in people with chronic pain who experience sleep disturbance (e.g., Horne & Shackell, 1991; Moldofsky, Scarisbrick, England, & Smythe, 1975; Roizenblatt et al., 2001). Roizenblatt et al. (2001) identified three distinct patterns of alpha sleep activity in patients with chronic pain, which were phasic alpha (i.e., simultaneous with delta activity), tonic alpha (i.e., continuous throughout NREM sleep) and low alpha activity. Of 40 patients with chronic pain, 50% showed phasic alpha activity, 20% tonic alpha activity and 30% low alpha activity. All patients with phasic alpha activity reported poor sleep, low sleep efficiency, less total sleep time, less slow wave sleep and worse pain compared to other subgroups (i.e., patients with tonic alpha activity and patients with low alpha activity). This interference of alpha activity has been linked to nonrestorative sleep in chronic pain.

Several studies have reported an increased rate of Cyclic Alternating Pattern (CAP) in people with chronic pain (e.g., Parrino, Ferri, Bruni, & Terzano, 2012; Rizzi et al., 2004). CAP is a marker of sleep instability, derived from PSG data. It is a periodic activity comprises two alternate EEG patterns that measures the presence of NREM sleep and the extent to which changes occur between these patterns over time (Krystal & Edinger, 2008; Terzano et al., 1985). CAP "*corresponds to a prolonged oscillation of the arousal level between two reciprocal functional states termed phase A (greater arousal) and phase B (lesser arousal). It is thought to represent a condition of instability that manifests the brain's fatigue in preserving and regulating the macrostructure of sleep*" (Rizzi et al., 2004, p. 1193). CAP rate (NREM sleep) is calculated based on a percentage ratio of total CAP time to total NREM sleep time. To evaluate the presence of CAP, Rizzi et al. (2004) compared an overnight PSG data of patients with fibromyalgia (*n*= 45) with healthy individuals (*n*= 36). The authors found that the CAP rate was significantly increased in patients with fibromyalgia than the control group. Findings also revealed that the CAP rate had positive association with the severity of clinical symptoms and negative association with sleep efficiency in fibromyalgia group. These results indicate that the CAP reflects sleep instability and correlates with pain symptoms.

Together, these studies provide insights into the disturbance of sleep patterns in chronic pain population. Importantly, the characteristics of sleep disturbance in patients with chronic pain are remarkably similar to the individuals with primary insomnia. Tang et al. (2012) did not find any significant difference between the pain-related insomnia group and primary insomnia group in their pattern and severity of sleep. These authors recruited 137 patients with chronic pain comorbid insomnia (pain-related insomnia group) and 33 patients with primary insomnia (primary insomnia group). Participants of both groups completed a battery of questionnaire comprising questions on sleep patterns, psychological attributes (level of anxiety, depression, health anxiety and tendency to worry) and cognitive-behavioural processes (sleep-related anxiety, dysfunctional beliefs about sleep and pre-sleep arousal) related with the persistence of insomnia. Similar to the primary insomnia group, the pain-related insomnia group had mean ISI of 20 indicating severe clinical insomnia and had problems sleeping for 5 to 6 nights in a week. The pain-related insomnia group reported levels of sleep-related anxiety and pre-sleep somatic arousal that matched with those reported by the primary insomnia group. These authors also found that pain intensity, depression, and pre-sleep cognitive arousal were significant predictors of insomnia severity within the pain-related insomnia group. Therefore, in order to understand the occurrence of sleep disturbance in chronic pain, it may be helpful to understand the theoretical models for the development and maintenance of primary insomnia. These models will be discussed in the subsequent section.

2.5 Insomnia models

2.5.1 Spielman's model

Spielman's model or 3P model (Spielman, Caruso, & Glovinsky, 1987) is one of the earliest models that explain the natural history of insomnia, how acute insomnia can become self-perpetuating and progress to chronic insomnia. Figure 2.2 shows the interaction of the three factors, namely *predisposing*, *precipitating* and *perpetuating*. The predisposing factors are predominantly biopsychosocial comprising biological factors (e.g., genetic, hyperarousal), psychological factors (e.g., excessive worry and rumination) and social factors (e.g., incompatible sleep schedule between spouses). The precipitating factors are life events that trigger sleep disturbances such as stress and medical illness. Therefore people who are exposed to the predisposing factors potentially increase their risk for insomnia and they might experience acute episodes triggered by precipitating factors. This will eventually develop into chronic insomnia via perpetuating factors. The perpetuating factors are maladaptive coping behaviours such as the tendency to compensate for lack of sleep by spending excessive amount of time in bed (e.g., going to bed early, getting out of bed later) to prolong the opportunity to sleep. In the context of chronic pain, patients with chronic pain are predisposed to arousal (e.g., Smith, Perlis, Smith, Giles, & Carmody, 2000) and the precipitating factor such as constant pain may trigger their sleep disturbances (e.g., Ødegård, Sand, Engstrøm, Zwart, & Hagen, 2013). The use of maladaptive coping such as staying in bed awake for a long period of time acts as perpetuating factor in developing acute sleep problems into chronic insomnia. The advantage of Spielman's model is it provides a framework to conceptualise the development from acute to chronic insomnia in the context of chronic pain based on the interaction of the three factors (predisposing, precipitating and perpetuating). However, this model is a generic model and hence it does not specify the perpetuating factors that could explain how poor sleep could affect next day functioning such as physical inactivity in people with chronic pain.

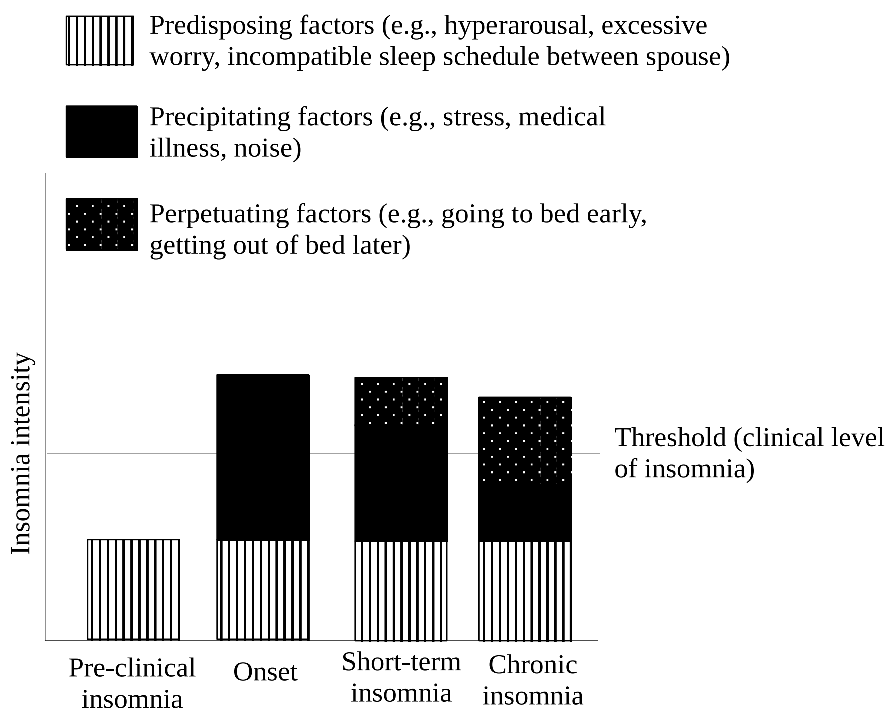

Figure 2.2 Spielman's model (Adapted from Spielman et al., 1987)

2.5.2 Morin’s model

Morin’s model (1993) presents the variables responsible for insomnia (see Figure 2.3). Morin’s model acknowledges the role of hyperarousal as the mediating feature of insomnia. This arousal includes emotional, cognitive and physiological. Greater level of arousal interrupts the balance between sleep and wakefulness. Maladaptive habits such as excessive time in bed, irregular sleep schedule, daytime napping and sleep-incompatible activities are also responsible for insomnia. The model recognizes the novel contribution of dysfunctional beliefs and attitudes about sleep on the development and maintenance of insomnia. These dysfunctional cognitions include worry over sleep loss, rumination over consequences, unrealistic expectations and misattribution/ amplifications. The model highlights the common next-day consequences of insomnia. These consequences involve mood disturbance, fatigue, performance impairments and social discomfort. In the context of chronic pain, pain may aggravate emotional, cognitive and physiological arousal. The dysfunctional cognitions were not only about rumination and worrying over sleep loss, but also dysfunctional sleep beliefs about the sleep-pain interaction (Afolalu, Moore, Ramlee, Goodchild, & Tang, 2016). For example, "*with the pain, I can never get myself comfortable in bed*", "*I know I can't sleep through the night because the pain will wake me up*" or "*Not sleeping well is going to make my pain worse the next day*". These maladaptive beliefs are potential factors perpetuating pain-related insomnia in patients with chronic pain. Physical inactivity during the day could be one of the maladaptive habits as a result of not sleeping. Potentially if pain is to be incorporated in the Morin's model, pain could also be a consequence of sleep disturbance.

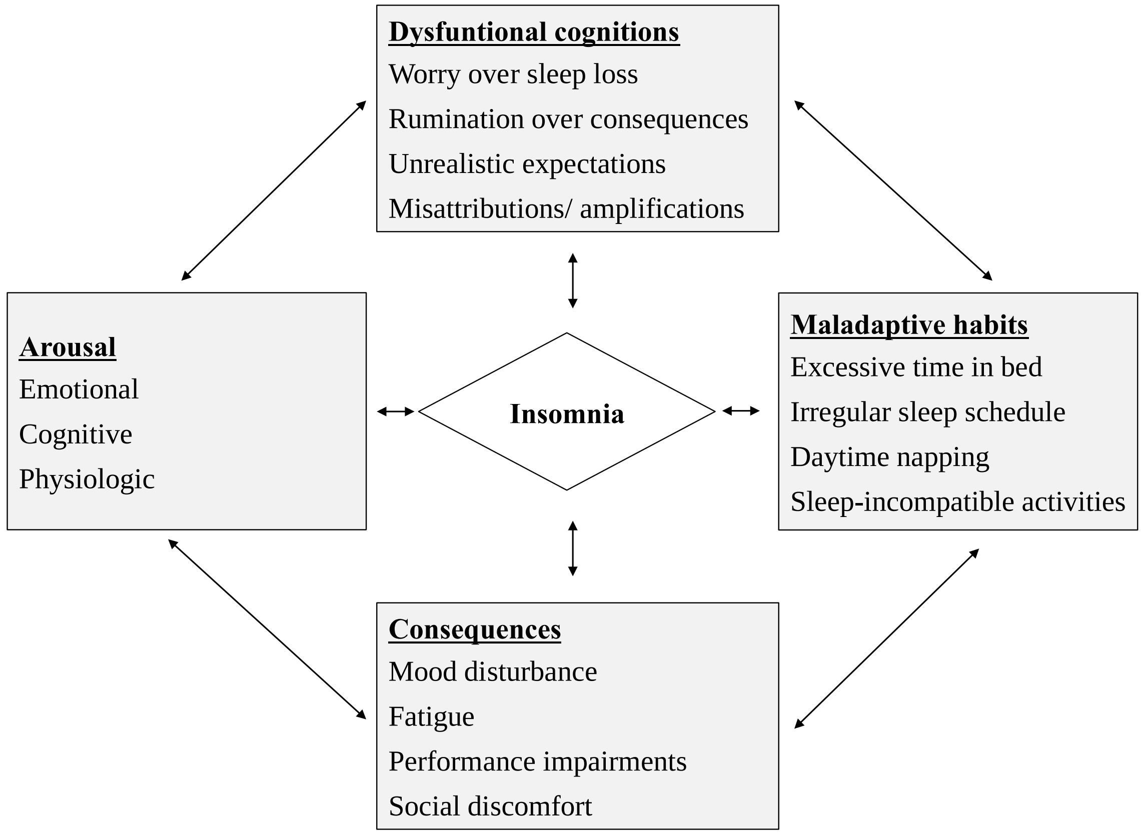

Figure 2.3 Morin's model (Adapted from Morin, 1993)

2.5.3 Lundh and Broman's model

Lundh and Broman's model (Lundh & Broman, 2000; see Figure 2.4) proposed that insomnia is a manifestation of the interaction between sleep-interfering processes (arousal) and sleep-interpreting processes (appraisal). This model is more comprehensive as it differentiates the role of arousal and appraisal in the development and maintenance of insomnia. Sleep-interfering processes refer to cognitive, physiological and emotional arousal that occurs in response to stressful life events. The stressful life events include a high level of arousal, worry about sleeplessness and emotional conflicts in interpersonal relationships. Consequently, these psychological processes interfere with sleep and may influence an individual to engage in dysfunctional sleep interpreting processes. Sleep-interpreting processes are appraisals of sleep and daytime functioning such as attributions and dysfunctional beliefs about sleep and consequences of poor sleep. This model also highlights that perfectionism, as an appraisal process, is a potential vulnerability factor for insomnia. Vincent and Walker (2000) found that the insomnia group (*n*= 32, mean age= 46.91 years) showed higher level of maladaptive perfectionism than the healthy control group (*n*= 26, mean age= 39.65 years). Consequently, this appraisal process exacerbates insomnia/ sleep complaints. In the context of chronic pain, pain could be a factor that contributes to the sleep-interfering and sleep-interpreting process. Pain could trigger arousal (sleep-interfering process) which lead to the perception of poor sleep quality (sleep-interpreting process). This appraisal would affect other outcomes such as physical inactivity.

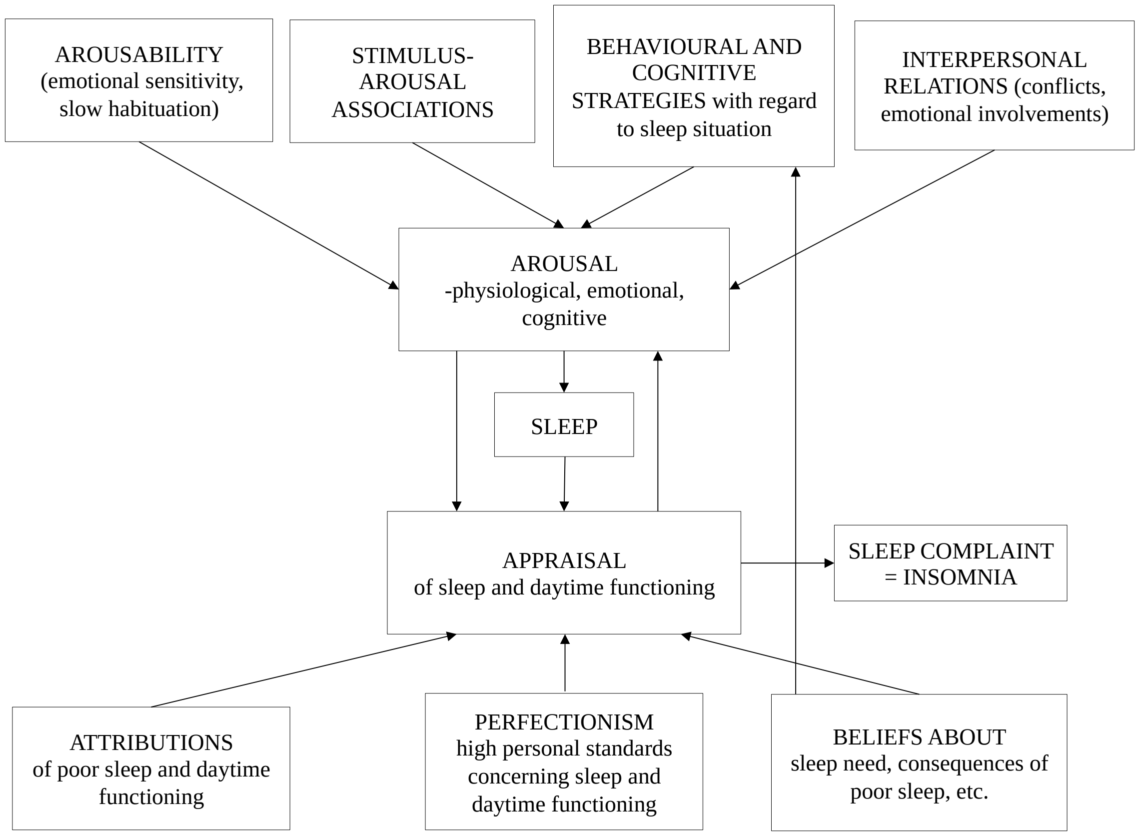

Figure 2.4 Lund and Broman's model (Adapted from Lund & Broman, 2000)

2.5.4 Harvey's model

The cognitive model by Harvey (Harvey, 2002; see Figure 2.5) suggested that excessive negatively toned cognitive activity (i.e., excessive worry about not getting enough sleep and its daytime consequences) triggers both autonomic arousal and emotional distress in people with insomnia. This model is based on anxiety disorder models. In an early study, Lichstein and Rosenthal (1980) reported that people with insomnia suffer from excessive worry and intrusive thoughts. Lichstein and Rosenthal (1980) conducted a survey in a sample of 296 people with insomnia and they found that cognitive disturbance was cited 10 times more likely than somatic arousal as the primary factor of the insomnia. During the presleep period, people with insomnia occupied their cognition processes with worries, problems and noises in the environment (Harvey, 2000). According to Harvey's cognitive model, the anxious state in turn leads to selective attention towards and monitoring of internal (e.g., body sensations) and external (e.g., the environment) sleep-related threats. Clock monitoring during presleep has been identified as a habit that induces worries in individuals with insomnia. Tang, Schmidt and Harvey (2007) conducted an experiment to examine the effect of clock monitoring during presleep on sleep misperception in people with primary insomnia. Participants were randomly assigned to either the clock-monitoring group (n= 19) or the display unit-monitoring group (n= 19). On a scale 0 (not at all) to 10 (very much), participants were asked to rate to index sleep-related worry. Out of six items, four items were found to have significant differences between the clock-monitoring group and the display unit-monitoring group. The items were "to what extent did the task make you worry that you are not getting enough sleep" (p= .007), "to what extent did the task make you worry about not being able to fall asleep" (p= .001), "to what extent did the task make it difficult to fall asleep" (p= .005) and, "to what extent did the task make me become aware of time passing" (p= .009). The participants in the clock-monitoring group rated all the items to be more worry provoking and sleep interfering than the participants in the display-unit group. Findings also indicated that the participants in the clock-monitoring group over-estimated their sleep onset latency on the experimental night compared to the baseline night. Misperception of sleep occurs when both the anxiety and attentional processes trick the person into believing that they obtained significantly less sleep that they actually obtained and/or that their daytime performance will be significantly worse than it actually was. This cycle further escalates anxiety, use of safety behaviours (e.g., cancelling appointments and napping during the day) and erroneous beliefs about sleep. This model also highlights insomnia is a 24-hour process (night and during the day). In the context of chronic pain, Smith, Perlis, Carmody, Smith and Giles (2001) found that presleep cognitive arousal (such as thinking about pain and negative sleep related thoughts) contribute to sleep disturbance (*n*= 31, mean age= 42 years). The authors also demonstrated that greater presleep thoughts about environmental stimuli and pain severity were significantly associated with greater awakenings at nights. The excessive negatively toned cognitive activity about pain and the impact the pain is having on sleep, psychological and physical functioning trigger arousal and emotional distress. Eventually this would influence the judgement of sleep quality.

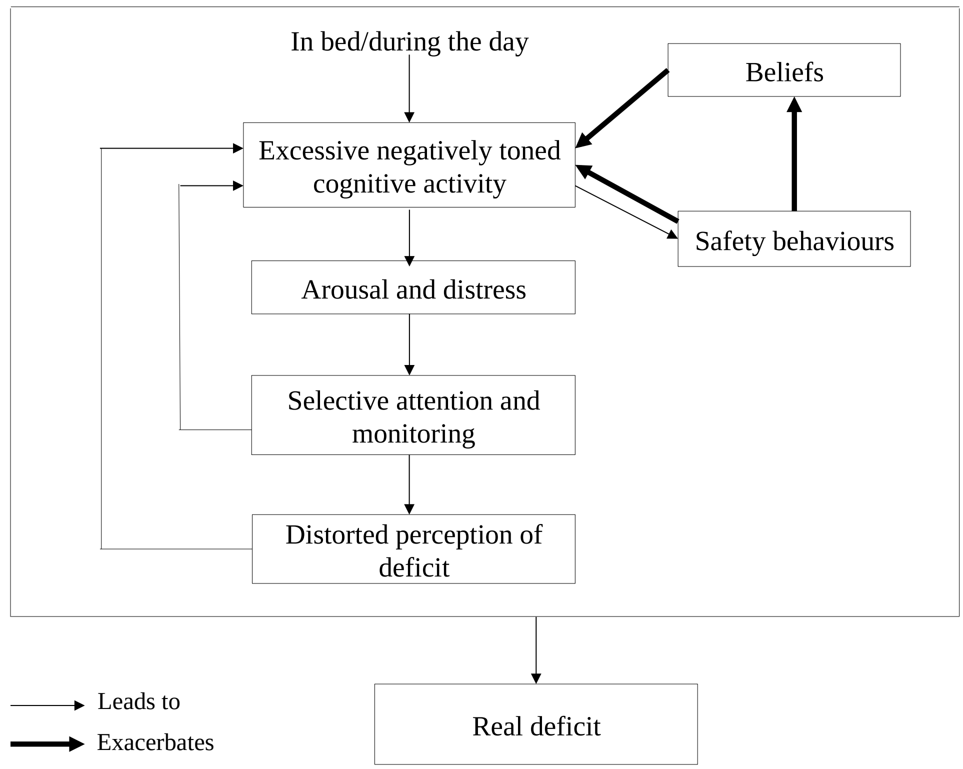

Figure 2.5 Harvey's model (Adapted from Harvey, 2002)

2.5.5 Espie et al.'s model

The Attention-Intention-Effort (A-I-E) model (Espie, Broomfield, MacMahon, Macphee, & Taylor, 2006; see Figure 2.6) viewed that normal sleep is an automatic process that occurs passively without conscious attention, intention and effort to sleep. It is an involuntary psychophysiological process. However, this sleep normalcy may be inhibited and insomnia results from the failure to inhibit wakefulness and initiate sleep without effort. The central mechanism of the model is the inhibition of sleep-related de-arousal. This occurs as a result of selective attention bias towards sleeps cues, leading to explicit intention to sleep and eventually engaging in active effort trying to fall asleep. For patients with chronic pain, the comorbid of poor sleep disturbance and pain are considered a stressful life event. Theadom and Cropley (2008) found that high perceived stress was significantly associated with greater sleep disturbance ($p<.05$) and higher daytime dysfunction ($p<.05$) in people with fibromyalgia ($n= 83$, mean age= 52.59). The experience of pain is likely an inhibition of normal sleep-related de-arousal. Based on the explicit intention component in the Espie's model, people with chronic pain would reduce their daytime physical activity or not do anything during the day which eventually will involve in direct/ indirect sleep effort.

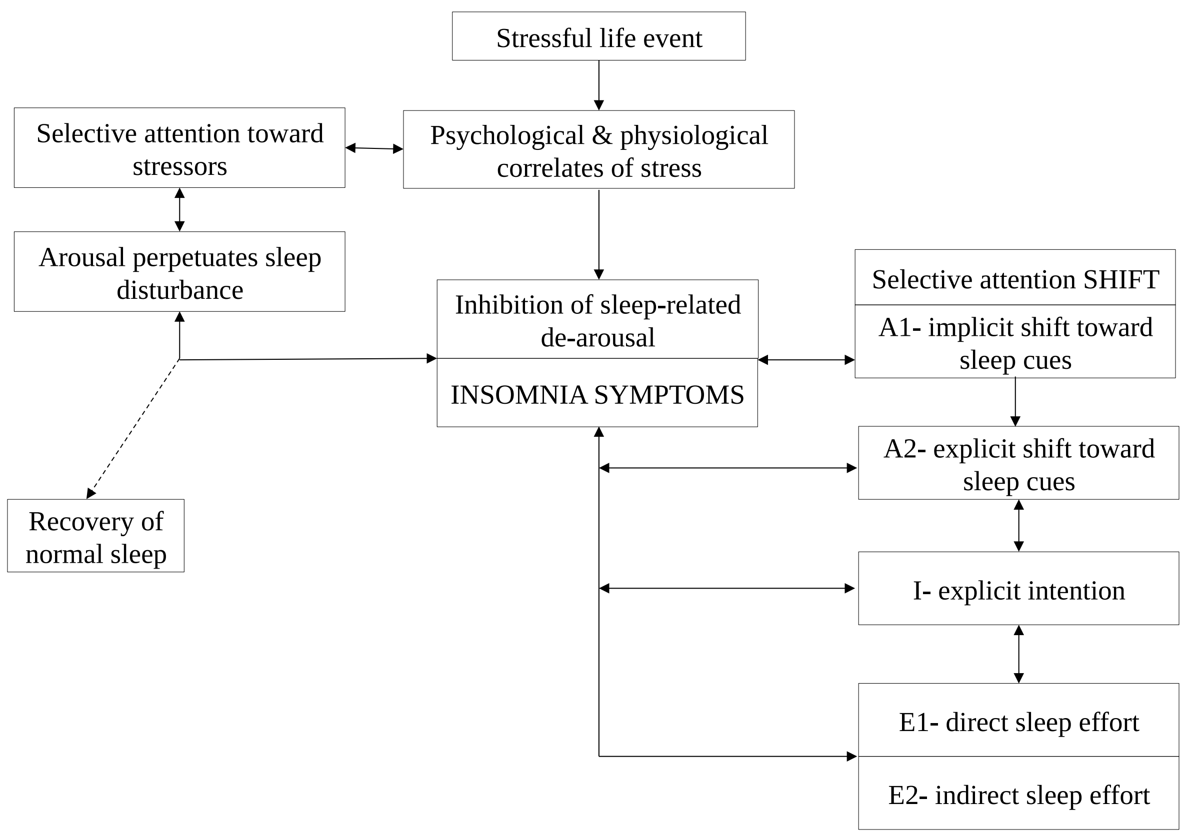

Figure 2.6 Espie at el.'s model (Adapted from Espie et al., 2006)

All of the models have highlighted some common underlying features in the development and maintenance of insomnia. However, they are generic, piecemeal and not coherent. In the context of chronic pain, pain could be a factor and/or consequence of sleep disturbance. Hence, the next sections will discuss evidence on how pain affects sleep and vice versa.

2.6 The relationship between pain and sleep

2.6.1 *Pain affects sleep*

There has been a growing number of studies that demonstrate pain could impact sleep. Lavigne et al. (2004) carried out an experimental study with healthy adults (*n*= 13, mean age= 24.2 years old) to examine the role of nociceptive stimulation in eliciting sleep arousal over all sleep stages. Participants underwent two experimental nights, which were one for the innocuous experiments (i.e., using vibrotactile and/or auditory) and the other for the noxious experiments (i.e., using intramuscular saline infusions). These stimulations were administered before sleep session and repeated during sleep. Participants completed questionnaires on sleep quality and pain in the morning. The analysis showed that the vibrotactile-auditory stimulations and noxious infusions significantly triggered more awakenings in N2 and REM. Participants also reported lower sleep quality following the nights with noxious stimulations compared to the baseline night. The findings highlight noxious stimuli can trigger arousals across all sleep stages.

Longitudinal studies have evaluated the relationship between pain and sleep at the population level (e.g., LeBlanc et al., 2009; Nicassio & Wallston, 1992; Ødegård et al., 2013; Tang et al., 2014). LeBlanc and colleagues (2009) conducted a postal survey in 464 good sleepers (mean age= 42.36 years) followed every 6 months and over the course of a year. At baseline, sleep variables were assessed using the Insomnia Severity Index, Pittsburgh Sleep Quality Index and questions about any previous episodes of insomnia and familial history of insomnia. Bodily pain was assessed using the SF-12, with a higher score indicating less pain. Participants were classified into one of three groups: insomnia syndrome group, insomnia symptoms group or good sleepers. Insomnia syndrome group consisted of those who met all the diagnostic criteria for insomnia. The diagnostic criteria were based on DSM-IV-TR, the International of Classification of Diseases, 10^{th} Edition (ICD-10) and on the utilisation of sleep-promoting products (i.e., both prescribed and over-the-counter). Meanwhile, insomnia symptoms group consisted of those who did not meet all the diagnostic criteria of an insomnia syndrome but presented some symptoms of initial, maintenance or late insomnia ≥3 nights per week. The authors found that one-year incidence rates for insomnia symptoms were 30.7% and insomnia syndrome was 7.4%. Higher bodily pain at baseline was a significant predictor of a new onset of an insomnia syndrome (OR=0.98). Similarly, Tang et al. (2014) conducted a prospective study in a larger and older sample involving 6676 insomnia-free participants (mean age= 64.2 years) followed over a 3-year period. Both widespread pain (AOR= 2.13; widespread pain refers to the presence of pain in the left and right hand sides of the body, above and below the waist and in the axial skeleton based on American College of Rheumatology criteria for widespread pain) and some pain (AOR= 1.57; some pain refers to participants who reported pain but did not meet the American College of Rheumatology criteria for widespread pain) significantly predicted the risk of insomnia onset at 3 years. The risk of insomnia onset remained significant even after adjusting for age, gender, socio-economic class, education, anxiety, depression, sleep and comorbidity at baseline.

Using data drawn from a large-scale health surveys (HUNT), Ødegård et al. (2013) examined the influence of headache, chronic musculoskeletal complaints (CMSCs; i.e., pain and/or stiffness in muscles and joints) and comorbid headache and CMSCs on the risk of insomnia onset 11 years later. A total of 27185 participants completed the surveys at both assessments and 19271 of them were identified as insomnia-free at baseline. Logistic regression analysis revealed that both headache and CMSCs independently predicted insomnia onset at follow up and it was most pronounced among those with headache ≥7 days/month (OR= 2.2) and those with CMSCs meeting the 1990 American College of Rheumatology (ARC) criteria (OR = 2.0). Furthermore, having comorbid headache and CMSCs (OR= 2.0) predisposed more strongly to insomnia onset than having headache (OR= 1.5) and CMSCs (OR= 1.6) alone. Odegard et al.'s (2013) study provides evidence that the different types of pain and its frequency could influence insomnia development differently. Overall, these longitudinal studies have demonstrated that chronic pain significantly predicts subsequent sleep disturbance or insomnia onset.

2.6.2 *Sleep affects pain*

The previous section has shown how pain affects sleep. This section now turns to the evidence on sleep affects pain. Several experimental studies have provided evidence that suggest sleep deprivation or fragmentation contributes directly in pain severity, sensitivity and tolerance in healthy individuals. Onen, Alloui, Gross, Eschallier and Dubray (2001) investigated the effects of total sleep deprivation, REM sleep and SWS interruption and sleep recovery on mechanical and thermal pain sensitivity in nine healthy male adults (mean age= 31 years old). Using a counterbalanced order, the participants were randomly assigned to undergo REM sleep and SWS interruption conditions. REM sleep and SWS were identified using polysomnography. Both conditions were separated by at least two weeks. The participants underwent six consecutive nights of laboratory testing for each condition: night 1 was for adaptation, night 2 was for baseline, night 3 was for total sleep deprivation (40 hours), night 4 and 5 were for either REM sleep or SWS interruption and, night 6 was for recovery (i.e., a night of undisturbed sleep). Mechanical pain threshold was assessed using an electronic pressure dolorimeter and thermal pain was assessed using a microprocessor-controlled thermode. The results showed that total sleep deprivation significantly decreased mechanical pain threshold by 8%. However, there was no significant difference in thermal pain threshold. The lack of significant difference in thermal pain threshold might be attribute to the possible interference of skin temperature and low capacity of thermal tests to detect small changes in thermal pain threshold. The findings demonstrated that possibly sleep deprivation causes nonspecific hyperalgesia to the mechanical stimuli. Haack, Sanchez and Mullington (2007) also found that prolonged partial sleep restriction (i.e., from 8 hours of sleep to 4 hours of sleep for 12 nights) intensified inflammatory responses in healthy individuals. Moreover, sleep deprivation can impair central pain modulation by reducing the endogenous pain inhibition (Smith, Edwards, McCann, & Haythornthwaite, 2007). Smith et al. (2007) investigated whether partial sleep loss altered endogenous pain inhibition and reports of spontaneous pain in 32 healthy females. Participants underwent 7 consecutive nights of polysomnography studies. Night 1 was for adaptation in which participants familiarised themselves with the polysomnography procedure and Night 2 was for a baseline night. Starting Night 3, participants were randomly assigned to one of the three conditions: control (*n*= 12), forced awakening (*n*= 10) or restricted sleep (*n*= 10). Participants in the control condition sleep undisturbed with an 8-hour sleep opportunity. Participants in the forced awakening condition underwent partial sleep deprivation as they were forced to awake at random intervals throughout the night. Meanwhile participants in the restricted sleep condition underwent delayed bedtime but kept a fixed wake time. The restricted sleep condition was designed to serve as a comparison condition to examine whether disrupted sleep continuity affects pain sensitivity beyond simple sleep loss. On Night 6, the participants in both forced awakening and restricted sleep conditions were required to remain awake for 36 hours (total sleep deprivation). On Night 7, all participants underwent recovery night in which they were allowed to sleep undisturbed for 11 hours. As for the pain testing, all participants completed two assessment sessions; (1) 30 minutes after awakening in the morning, (2) late afternoon between 4pm and 5pm.

Each pain assessment session comprised testing of pressure pain threshold, thermal sensitivity and pain inhibition.

Several longitudinal studies have also demonstrated the role of sleep in influencing pain (e.g., Gupta et al., 2007; Mork & Nilsen, 2012; Morphy, Dunn, Lewis, Boardman, & Croft, 2007; Nitter, Pripp, & Forseth, 2012). Mork and Nilsen (2012) examined the link between self-reported sleep disturbance and risk of fibromyalgia in 12350 healthy adult women. The authors found 327 women reported an incidence of fibromyalgia at follow-up 11-12 years later. The relative risk estimate was adjusted for age, body mass index, frequency of physical exercise, psychological wellbeing, smoking status and education. An association was found between sleep problems at baseline and risk of fibromyalgia at follow-up in women with sleep problems (Adjusted RR= 3.43). In addition, Morphy et al. (2007) found that insomnia at baseline significantly predicted widespread pain 12 months later in both adult men and women (unadjusted RR: 1.55; *n*= 1589). Insomnia in this study was based on self-report of having “trouble falling asleep on most nights” and/ or “wake up several times at night on most nights” and/ or “ trouble falling asleep on most nights” and/ or “wake up tired and worn out on most nights”. The relationship between insomnia and widespread pain remained significant after the effects of age and gender were adjusted (RR: 1.45).

Gupta et al. (2007) investigated the role of sleep problems in the development of chronic widespread pain among pain-free adults aged 25 to 65 years old. Of the 3171 pain-free adults, 324 participants developed chronic widespread pain at follow-up 15 months later. Scorings from three scales independently predicted the development of chronic widespread pain, which were Somatic Symptom Checklist (OR: 1.8), Illness Behaviour subscale of the Illness Attitude Scales (OR: 3.3), and the Sleep Problem Scale (OR: 2.7). Compared to participants who scored low on all the three scales, those who scored high were 12 times more likely to develop new chronic widespread pain 15 months later.

Nitter et al. (2012) followed up 1338 women in Norway over 17 years at three time points; in 1990 (range age= 20-29 years), 1995 (range age= 30-39 years) and 2007(range age= 40-49 years). They found that the development of chronic pain in initially pain-free women at follow up was 44%, with impaired sleep quality being a significant predictor of chronic pain (OR: 2.1). Impaired sleep quality was assessed using closed-ended questions (e.g., *Do you often wake up at night or have poor sleep?*; *Do you feel refreshed in the morning?*) with two dichotomous answers (yes/ no). Meanwhile, pain was measured using a question (i.e., *Did you have pain and/ or stiffness for at least three consecutive months during the last year at any of these sites? Joints, muscles, back, whole body*) with two dichotomous answer (yes/ no). The participants were classified into (1) chronic widespread pain if they reported pain in the combination of “muscles”, “joints” and “back” or any combination involving “whole body”, (2) chronic regional pain if they reported pain in either “muscles”, “joints”, or “back” or any combination of the two, (3) No chronic pain if they answers “No” to the question. Taken together, findings from these experimental and longitudinal studies highlight that sleep disturbance has a negative impact on the development of pain and its intensity and severity.

2.6.3 *Bidirectional relationships between pain and sleep on a daily basis*

This section will discuss some evidence on the potential bi-directional relationships between sleep and pain. The association between pain and sleep is likely to be bidirectional, such that sleep disturbance increases pain sensitivity and pain worsens sleep. Several previous studies have used daily process study to investigate the day-to-day relationship between pain and sleep (e.g., Affleck et al., 1996; Edwards, Almeida, Klick, Haythornthwaite, & Smith, 2008; Raymond, Nielsen, Lavigne, Manzini, & Choinie, 2001; Tang, Goodchild, Sanborn, Howard, & Salkovskis, 2012). However the findings are not always consistent. The overall balance of the findings suggests that sleep has a greater influence on pain than pain on sleep. Daily process study or micro-longitudinal study is an intensive design with time-specific monitoring procedure of pain and sleep over a certain period of time (Affleck, Zautra, Tennen, & Armeli, 1999; Smith, Nasir, Campbell & Okonkwo, 2012). Specifically this design requires the participants to collect data of their own pain and sleep experience repeatedly and frequently (e.g., three times a day for seven days). This design typically utilises multilevel modelling to examine lagged relationship or within-person day-to-day interaction between pain and sleep. According to Tennen and Affleck (1996), this design has the advantage to detect the rapid daily fluctuations in pain and sleep.

Affleck et al. (1996) found a significant bidirectional within-person relationship between pain attention and sleep quality in 50 women with fibromyalgia. Results suggested that a night of worse sleep quality was followed by greater pain next day, and greater pain during the day was followed by a night of poorer sleep. However, the association became non-significant when pain attention was controlled for. This result was derived from 30 days of self-monitoring data. Similarly, using structural equation model for over a week report data, duration of reported sleep (i.e., long sleep of ≥ 9 hours and short sleep of < 6 hours) was found to predict greater pain next day and pain predicted sleep duration in 971 participants (Edwards et al., 2008).

Other researchers, however, who have looked at the bidirectional association between pain and sleep have found that the association did not seem to be reciprocal (Raymond et al., 2001; Tang et al., 2012). Using a daily process design, Tang et al. (2012) investigated the effect of presleep pain on subsequent sleep and sleep on pain reports the next day in 119 patients with chronic pain. Participants were trained to monitor their pain, sleep, mood and presleep arousal for a week using electronic diary and actigraphy, in their natural living and sleeping environment. Multilevel models revealed that presleep pain was not a significant and reliable predictor of subsequent overall sleep quality. However, sleep quality significantly predicted pain during the first half of the day, with higher sleep quality predicting less pain during the day. Whilst sleep quality was found to be a consistent predictor of pain the next day, findings suggested that the pain-reliving effect of sleep was only evident during the first half of the day.

Raymond et al. (2001) investigated the daily temporal association between sleep quality and pain intensity in 28 hospitalised adult burn patients (mean age= 34.8 years) during the first week of hospitalisation. Participants took part in a structured interview upon waking for five consecutive mornings (number of observations= 140). The interviews were 10 to 15 minutes long. During the interview, participants were asked to rate their sleep quality of the previous night using a visual analogue scale, total sleep time, number of awakenings during the night and the presence of nightmares. During the day, participants were asked to rate their pain intensity using a numerical rating scale from 0 (no pain at all) to 10 (unbearable pain). The pain ratings were taken every four hours. Pooled cross-sectional regression analyses revealed that poor sleep quality of the previous night was followed by a more painful day. However pain during the day was not a significant predictor of the subsequent sleep. Importantly, findings from daily process studies highlight that sleep appears to be a stronger, more reliable predictor of pain than pain on sleep (Finan, Goodin, & Smith, 2013). Overall, these studies highlight the comorbid nature of pain and sleep disturbance and their temporal association but findings for the bidirectional relationship between pain and sleep are somewhat less consistent. Possibly, further investigations are required to examine the factors mediating or moderating the relationship between sleep and pain. For example, depression (Naughton, Ashworth, & Skevington, 2007) and physical activity (Tang et al., 2012) may be mediators in the sleep-pain relationship. Physical activity will be the focus in the next sections.

2.7 Physical activity and health outcomes

The World Health Organization (WHO, 2010) has recommended adults aged 18-64 years old should at least engage in 150 minutes of moderate-intensity aerobic physical activity throughout the week. *Aerobic physical activity* refers to endurance activity that increases cardiorespiratory fitness such as running, jumping rope, brisk walking, swimming and bicycling. Meanwhile *intensity* is the extent to which the activity is being performed and *moderate-intensity* is defined as activity that is performed at 3.0-5.9 times the intensity of rest on an absolute scale. For instance, *moderate-intensity* physical activity is rated as 5 on a scale of 0-10 relative to an individual’s personal capacity. In addition, moderate- or vigorous-intensity activities performed as a part of daily routine such as brisk walking to work and gardening with shovel performed in bouts of 10 minutes can be counted as recommended amount and types of physical activity (Haskell et al., 2007). *Vigorous-intensity* is defined as activity that is performed at 6.0 or more time the intensity of rest. For instance, *vigorous-intensity* physical activity is rated as 7 on a scale of 0-10 relative to an individual’s personal capacity. Following the WHO recommendations, individuals should perform moderate-intensity aerobic physical activity for a minimum of 30 minutes on five days in a week or vigorous-intensity aerobic physical activity for a minimum of 20 minutes on three days in a week (Haskell et al., 2007).

Regular physical activity has been associated with a wide range of better health outcomes. Regular physical activity improves mental health and reduces the risk of cardiovascular disease, obesity, breast and colon cancer, diabetes, hypertension, osteoporosis, all-cause mortality (Bauman, Merom, Bull, Buchner, & Fiatarone Singh, 2016; Hu et al., 2004; Kriska et al., 2003; Reiner, Niermann, Jekauc, & Woll, 2013; Warburton, Nicol, & Bredin, 2006; WHO, 2010). Using The Nurses’ Health Study survey, Hu et al. (2004) followed-up 116564 women who were free from cardiovascular disease and cancer to examine the link between physical activity, body-mass index (BMI) and mortality. Of 10282 deaths, 2370 die from cardiovascular disease, 5223 from cancer and 2689 from other causes. Hu et al. (2004) classified the participants into nine groups based on the BMI which were <21, 21.0-22.9, 23.0-24.9, 25.0-26.9, 27.0-29.9, 30.0-32.9, 33.0-34.9, 35.0-39.9 and ≥40. Physical activity were divided into three levels which were those who spent ≥3.5 hours, 1.0-3.4 hours and <1.0 hour exercising per week. They found that higher level of physical activity is beneficial at all levels of BMI. In addition, the authors investigated the combined effects of physical activity and BMI. Compared with the participants who were active (i.e., spent ≥3.5 hours of exercise in a week) and lean (had BMI of ≤25), the relative risks of death were 1.55 for the participants who were inactive (i.e., spend less than 3.5 hours of exercise in a week) and lean, 1.91 for the participants who were active but obese (had BMI of ≥30), and 2.42 for the participants who were inactive and obese. The relative risks were adjusted for age, smoking status, parental history (i.e., coronary heart disease, menopausal status and hormone use) and alcohol consumption. These results are consistent with the systematic review carried out by Reiner et al. (2013) on the influence of physical inactivity on obesity, heart disease, type 2 diabetes mellitus, Alzheimer's disease and dementia. The findings showed that higher physical activity level was associated with less weight gain, low occurrence of heart disease, lower incidence of type 2 diabetes mellitus and decrease risk of developing dementia. Indeed, studies have shown that physical inactivity in chronic pain population was associated with more physical and mental health problems such as depression and obesity (Huijnen et al., 2010; Okifuji, Donaldson, Barck, & Fine, 2010). In summary, these findings show low level of physical activity is associated with poorer health outcomes.

2.8 Measures of physical activity

There are similarities between sleep and physical activity measurements in that physical activity can also be assessed using objective and self-report measures. An example of objective measure is the use of ambulatory activity monitor. Meanwhile examples of self-report measures are questionnaires and activity diaries.

Objective measure of physical activity can be carried out with the use of ambulatory activity monitoring. Ambulatory activity monitor uses devices to record activity, posture, and movement continuously in the natural environment (Bussmann, Ebner-Priemer, & Fahrenberg, 2009). The ambulatory activity monitors may differ from each other depending on, for example, types of sensor (e.g., mechanical, accelerometer), data storage, transmission, processing and analysis, number of measurement axes (e.g., two-, three- dimensional). The triaxial accelerometer could detect different postural transitions such as stand to sit and duration of different types of activity such as walking (Najafi, Wrobel, & Armstrong, 2008; Najafi et al., 2003). This ambulatory activity monitor is attached to the limbs. In addition, some of the activity monitors are also equipped with heart rate measure, body temperature and algorithms to estimate energy expenditure. This ambulatory activity monitor has advantages of accurate estimation of physical activity because it records physical activity as it occurs, captures a real time information of physical activity and ecologically valid. However, some of the ambulatory activity monitor may bring discomfort to the participant and limited to the battery life and storage capacity.

Examples of the questionnaires that are used to measure physical activity are the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003), the General Activity Scale of the Multidimensional Pain Inventory (MPI; Kerns, Turk, & Rudy, 1985), the Leisure Time Physical Activity Instrument (LTPAI; Mannerkorpi & Hernelid, 2005) and the Physical Activity at Home and Work Instrument (PAHWI; Mannerkorpi & Hernelid, 2005). Typically, the questionnaires comprise items asking participants to recall the amount of time spent in performing various types of activities in a week. Types of activity are generally classified into light, moderate and vigorous. For instance, items on IPAQ ask "*During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling?*" and "*How much time did you usually spend doing vigorous physical activities on one of those days? (hours per day, minutes per day)*". The advantages of questionnaires are simple, inexpensive and easy to administer specifically in large sample size. However information from questionnaires are prone to recall biases.

Activity diaries or logs are also used to measure physical activity. Typically participants complete the diary for a specific period such as a week. For example, Vendrig and Lousberg (1997) used seven-point likert scales (0-6) in the diary in which they asked participants to rate the activity from "0= rest, lying, doing nothing" to "6= heavy physical work". Some studies also asked participants to list down activities that could increase and/or decrease their pain and some of them were sitting, walking, vacuum cleaning and lying down (Linton, 1985). Although an activity diary/ log is feasible specifically in a large sample size and could record participant's own estimate of physical activity, this approach can be burdensome to a participant and missing data could occur as a result of lack of adherence to complete the diary/ log. In addition, the diary/log is subject to missing information such as the intensity or category of physical activity and the data is also subject to social desirability biases (Polatin & Mayer, 2001).

Taken together, it is essential to identify measures of physical activity that are suitable for the sample, duration of the study and types of physical activity. There is overlap between sleep and physical activity measures. In the subsequent chapters, the studies used sleep diary, activity diary and objective measures to assess sleep and physical activity.

2.9 The relationship between physical activity and sleep

2.9.1 Physical activity affects sleep

It has been widely assumed that regular physical activity promotes better sleep. In one of the early epidemiological survey conducted by Urponen, Vuori, Hasan and Partinen (1988) in Finland found that participants believe exercise had a positive effect on sleep. Urponen et al. (1988) asked 1190 participants (age ranged 36 to 50 years) an open-ended question to state three practices, habits or actions that promote sleep quality. Findings show that both men (33%) and women (30%) across ages also reported exercise as the most important factor influencing sleep quality, compared with reading/ listening to music (men= 14%, women= 23%) and taking shower/ sauna (men= 9%, women= 9%). Besides, the National Sleep Foundation has recommended "exercise daily" as one of the healthy tips to get a better sleep (National Sleep Foundation).

Ohida et al. (2001) carried out a large cross-sectional survey to investigate the association between lifestyle, health status factors and sleep loss in 31260 participants in Japan. Lifestyle comprised habitual exercise, eating regularity, food variety and volume of meals. Meanwhile sleep consisted of two questions which were (1) "*Do you always get sufficient sleep that you need?*" and (2) "*how many hours on average do you sleep at night?*". The participants were grouped into "subjective insufficient sleep" if they answered "insufficient" or "very insufficient" to question 1. Participants were considered to have "short sleep duration" if they indicated they had fewer than five or five to six hours sleep. Ohida et al. (2001) found that lack of regular exercise was associated with subjective insufficient sleep (OR: 1.32). However no significant association was found between lack of regular exercise and short sleep duration. Therefore, the authors suggest that engaging in a regular exercise may contribute to perception of getting sufficient sleep regardless of the short duration of sleep. But causality cannot be drawn from the finding, as this is a cross-sectional analysis. Low physical activity could be an outcome of poor sleep.

Buman, Hekler, Bliwise and King (2011) conducted a 12-month randomised controlled trial (RCT) to examine the effect of exercise on objective sleep parameters among underactive (i.e., 60 minutes per week of moderate or more vigorous physical activity over the previous six months) adults aged ≥55 years with mild to moderate sleep complaints (*n*= 66, mean age= 61.42). Participants were assigned to either control or exercise group. The participants in the control group attended weekly classes on health education. Meanwhile, the participants in the exercise group attended exercise classes 2 days in a week for 60 minutes and carried out home-based exercise 3 days in a week for 30 minutes. All the participants received a handout on the recommendations for sleep hygiene. Objective sleep was assessed using in-home PSG (i.e., Oxford Medilog MR95 digital recording system). At baseline, nine-channel PSG was assessed for three nights and at follow up 12 months later, nine-channel PSG was assessed again for two nights. In addition, at baseline, the PSQI was used to index sleep quality scores and the CHAMPS physical activity questionnaire was used to assess physical activity (i.e., in minutes of moderate intensity physical activity or more vigorous physical activity). Buman et al. (2011) found that participants in the exercise group showed significant improvement in sleep as indicated by more time spent asleep in stage 2 (p= .02) and less awakenings (p= .01). The findings suggest that exercise improves poor sleep among older adults.

Similarly, Jones et al. (2012) carried out a RCT to investigate the effectiveness of 8-form Tai Chi in improving fibromyalgia symptoms and functional mobility in patients with fibromyalgia. Fibromyalgia symptoms were measured using the Fibromyalgia Impact Questionnaire in which the score ranges from 0 to 100 with higher scores suggesting greater symptoms severity and poorer physical function. Sleep was measured using the PSQI. Patients were randomised to either Tai Chi (n= 51, mean age= 53.3 years) or educational group (n= 47, mean age= 54.8 years). The participants in the Tai Chi group were asked to practise Tai Chi twice weekly for 12 weeks (90 minutes for each session). At the same time, the participants in the educational group were asked to attend a psychoeducation class twice weekly for 12 weeks (90 minutes for each session). Findings indicated that patients in the Tai Chi group showed significant improvements in sleep compared to those in the educational group. This is consistent with findings from a systematic review and meta-analysis of RCT conducted by Langhorst, Klose, Dobos, Bernardy and Häuser (2013). Langhorst and colleagues (2013) evaluated the efficacy of meditative movement therapies in patients with fibromyalgia. The meditative movement therapies refer to Qigong, Tai Chi and Yoga. A meta-analysis was carried out on 7 studies comprising 372 patients with fibromyalgia (median age= 50 years). Results demonstrated that meditative movement therapies significantly reduced sleep disturbance (standardized mean difference= -0.61, CI= -.95, -.27, p= .0004). Overall, these studies indicate physical activity affects sleep. However, most of the studies were conducted in a pain-free population and adults aged over 50 years old. Besides, the magnitude effects in those studies were also varied. Further studies are required to investigate the effect of physical activity on sleep in a different demographic background (e.g., young adults, patients with chronic back pain).

2.9.2 Sleep affects physical activity

As previously discussed physical activity affects sleep, sleep could also affect physical activity. Studies have also looked into the link between sleep and physical activity in both healthy and chronic pain populations (e.g., Atkinson & Davenne, 2007; Baron, Reid, & Zee, 2013; Booth et al., 2012; Dam et al., 2008; Goldman et al., 2007;

Lang et al., 2016; Schmid et al., 2009; Smith et al., 2000; Tang & Sanborn, 2014). Using a cross-sectional design, Smith et al. (2000) found that self-reported sleep quality was significantly associated with the self-reported general activity level in 51 heterogeneous chronic pain patients (mean age= 44 years). Smith et al.'s study used the Pittsburgh Sleep Quality Index to assess sleep quality and the Multidimensional Pain Inventory to assess various aspect of chronic pain experience including general activity level. Whilst Smith et al.'s study highlights the correlation between sleep and physical activity, the study did not have data from a prospective self-report measure (e.g., sleep diary) or an objective measure that could provide sleep parameters such as total sleep time, sleep latency and sleep continuity. This is also true for physical activity.

Schmid et al. (2009) carried out an experimental study in 15 healthy normal-weight men (mean age= 27.1 years, mean BMI= 22.9) to examine the role of acute sleep loss in decreasing physical activity level. Physical activity was measured using accelerometry and sleep was recorded using polysomnography. Participants underwent two consecutive nights of 8 hours of sleep and two consecutive nights of 4 hours of sleep in ≥6 weeks apart. Schmidt et al. (2009) found that losing 4 hours sleep for two nights not only influenced the overall level of next day physical activity but also the intensity of physical activity. The intensity of physical activity was classified into three groups, which were low, middle and high. Participants spent significantly higher proportion of low intensity activities after 4 hours of sleep restriction compared to after 8 hours of sleep (p= 0.016).

Using actigraphy, Korszun et al. (2002) monitored the sleep patterns and activity level of patients with fibromyalgia with comorbid depression (*n*=6, mean age= 48 years), patients with fibromyalgia without comorbid depression (*n*= 16, mean age= 49.2 years), patients with depression (*n*= 9, mean age= 45.8 years) and healthy individuals (*n*= 28, mean age= 53.4 years) for 5-7 days. The findings revealed that the healthy control group demonstrated a regular sleep-wake pattern with undisturbed periods of sleep, 92.23% of sleep efficiency and high levels of daytime activity. Meanwhile, all the three patient groups showed interrupted sleep at night with sleep efficiency of 89.16% for patients with fibromyalgia without comorbid depression, 78.85% for patients with fibromyalgia comorbid depression and 73.48% for patients with depression. The authors found that although patients with fibromyalgia without comorbid depression exhibited poorer sleep quality compared to normal healthy individuals, they showed similar levels of daytime physical activity. Interestingly, both patients with fibromyalgia comorbid with depression and patients with depression demonstrated worse sleep quality and decreased physical activity. However, disturbed sleep and reduced physical activity levels were more prominent in patients with fibromyalgia comorbid with depression.

Goldman et al. (2007) conducted an observational study to investigate the relationship between sleep disturbance and daytime functioning in a large sample of older women (*n*= 2889, mean age= 83.5 years). Sleep was assessed using wrist actigraphy which the participants wore for an average of 4 nights (range 1 to 9 nights). Findings revealed that there were U-shaped relationship between total sleep time and walking speed, physical performance and functional limitation. Participants who slept less than six hours walked 3.5% slower than those who slept 6.0-6.8 hours. Participants who slept 7.5 hours or more took 4.1% longer to complete 5 chair stands than those who slept 6.8-7.5 hours. Goldman et al. (2007) also found that greater wake after sleep onset (WASO) was associated with slower walking speed, poorer physical performance and functional limitation. Participants who experienced 1.6 hours of WASO walked 9.1% slower than those who had 0.7 hours of WASO. Similar findings was also found in older men (*n*= 2862, mean age= 76.4 years) in which the participants who had WASO longer than 90 minutes showed slower walking speed compared to those who had WASO less than 90 minutes (Dam et al., 2008). Dam et al. (2008) also found U-shaped relationship between total sleep time and performance in grip strength. Participants who slept less than 6 hours and participants who slept more than 8 hours demonstrated the weakest grip. Findings from Dam et al.'s (2008) study highlights interrupted sleep could impact subsequent performance of daytime physical activity. In summary, these findings show that sleep affects next day physical activity and performance. However, these studies were limited to the relationship across individuals and they do not inform how sleep affects physical activity within a person.

2.9.3 The relationship between sleep and physical activity on a daily basis

Turning now to the discussion on the association between sleep and physical activity on a daily basis, as there are fluctuations and variations at the within-person level. Several studies have also found mixed findings on the within-person association between sleep and physical activity. Andrews, Strong, Meredith and D'Arrigo (2014) investigated the within-person link between daytime physical activity and sleep in people with non-malignant heterogeneous chronic pain (*n*= 50; mean age= 54.22 years). Participants were required to wear a triaxial accelerometer to assess their daytime physical activity and sleep for 5 days. Participants were also asked to complete a questionnaire in a palm-handled computer assessing pain, mood, catastrophising and stress six times a day at random intervals during the day. Multilevel models showed that higher fluctuations in daytime physical activity predicted shorter total sleep time and higher mean daytime physical activity levels predicted longer periods of wakefulness at night. The authors also found that higher number of pain locations predicted longer awakenings at night. Interestingly, although Andrews et al.'s study (2014) demonstrated the association between daytime physical activity and sleep, their findings also showed that performing high intensity level of daytime physical activity was associated with longer wakefulness at night. Andrews et al. (2014) points out that high fluctuations and high intensity daytime activity may reflect over-activity among patients with chronic pain. Hence, they suggested that intervention programme should incorporate activity modulation (e.g., activity scheduling, pacing education) to improve sleep quality in patients with chronic pain.

Tang and Sanborn (2014) carried out a daily process study to examine the effect of day-to-day fluctuations in sleep on physical activity the next day among 119 patients with chronic pain comorbid insomnia (mean age= 46 years). Using a daily process approach, participants were required to monitor their sleep and physical activity for a week in their natural living and sleeping environment. Sleep was measured using actigraphy (i.e., sleep efficiency) and an electronic diary (i.e., sleep quality, sleep efficiency), whereas physical activity was measured using actigraphy (i.e., mean activity score of each hour from noon to 11.00pm). In addition, morning pain and mood rating were measured using electronic diaries. Participants were asked to rate their morning pain (i.e., "*how much pain do you have right now?*"; 0= no pain at all, 10= a lot of pain) and mood (i.e., "*How would you describe your mood right now?*"; 0= very bad mood, 10= very good mood) on a numeric rating scale 0-10. Multilevel models showed that without any interventions, patients who had higher sleep quality spontaneously engaged in more physical activity the next day (p= .017). However, sleep efficiency derived from electronic diary (p= .190) and actigraphy (p= .474) were not found to be significant predictors of physical activity the next day. Besides, findings revealed that morning pain (p= .581) and morning mood (p= .079) were not significant predictors of physical activity the following day. The results also indicated that the temporal effect of sleep and physical activity in chronic pain patients was not explained by morning pain and morning mood.

Baron et al. (2013) conducted an intervention study to examine the bidirectional relationships between sleep and exercise in 11 women with insomnia (mean age= 61.27 years). Daily sleep was assessed using sleep logs and wrist actigraphy, whereas exercise was assessed using self-reported exercise log. The sleep logs asked the participants to record their bedtime, get up time, number of awakenings after sleep onset and subjective rating of sleep quality (i.e., 1-4: 1= excellent, 4= poor). The participants were asked to perform 30 minutes aerobic exercise 3 times in a week for 16 weeks. The aerobic exercise were walking, stationary bicycle or treadmill. Using multilevel models, Baron and colleagues (2013) found that longer sleep onset latency was followed by shorter exercise duration. However, exercise duration was not a significant predictor of sleep on the subsequent night. Taken together, these results of daily association between sleep and physical activity indicate that sleep is a consistent predictor of physical activity the next day at the within-person level and the possibility of sleep as an intervention to improve physical inactivity specifically in people with chronic pain.

2.10 Theoretical models of physical activity in people with chronic pain

The fear-avoidance model (FAM, see Figure 2.7) of pain-related disability has been used to explain the fear-avoidance beliefs about physical activity in people with chronic pain (Vlaeyen & Linton, 2000). Higher levels of fear-avoidance belief have been associated with lower levels of physical activity in chronic pain (Elfving, Andersson, & Grooten, 2007). People with chronic pain who show fear-avoidance will avoid physical and social activities (e.g., walking, sitting in a movie theatre) that could trigger pain and this eventually will decrease physical activity level (Hasenbring & Verbunt, 2010). According to the FAM, if pain experience is perceived as threatening (pain catastrophising, e.g., a patient interprets the pain as a result of severe pathology and that s/he does not have control over it), and consequently pain-related fear evolves. Pain catastrophising refers to "*an exaggerated negative 'mental set' brought to bear during actual or anticipated pain experience*" (Sullivan et al., 2001). For example, "I become afraid that the pain might get worse" (Sullivan, Bishop, & Pivik, 1995). This in turns leads to avoidance behaviours and hypervigilance to bodily sensations and subsequently spirals into a vicious and self-perpetuating fear-avoidance cycle that develops and maintains disability, depression, physical inactivity and pain. Hypervigilance is one's tendency to attend to threat-related stimuli, that is one's belief that movements can cause (re)injury and lead to pain and cues of (re)injury (Crombez, Eccleston, van Damme, Vlaeyen & Karoly, 2012; Vlaeyen & Linton, 2000). Whereas if pain experience is not perceived as threatening or catastrophic, there is no pain-related fear and hence patient is likely to confront daily activities. Thus, people with chronic pain will find it hard to return to a normal activity level when inactivity levels were induced by fear of movement/ (re)injury (Verbunt et al., 2003).

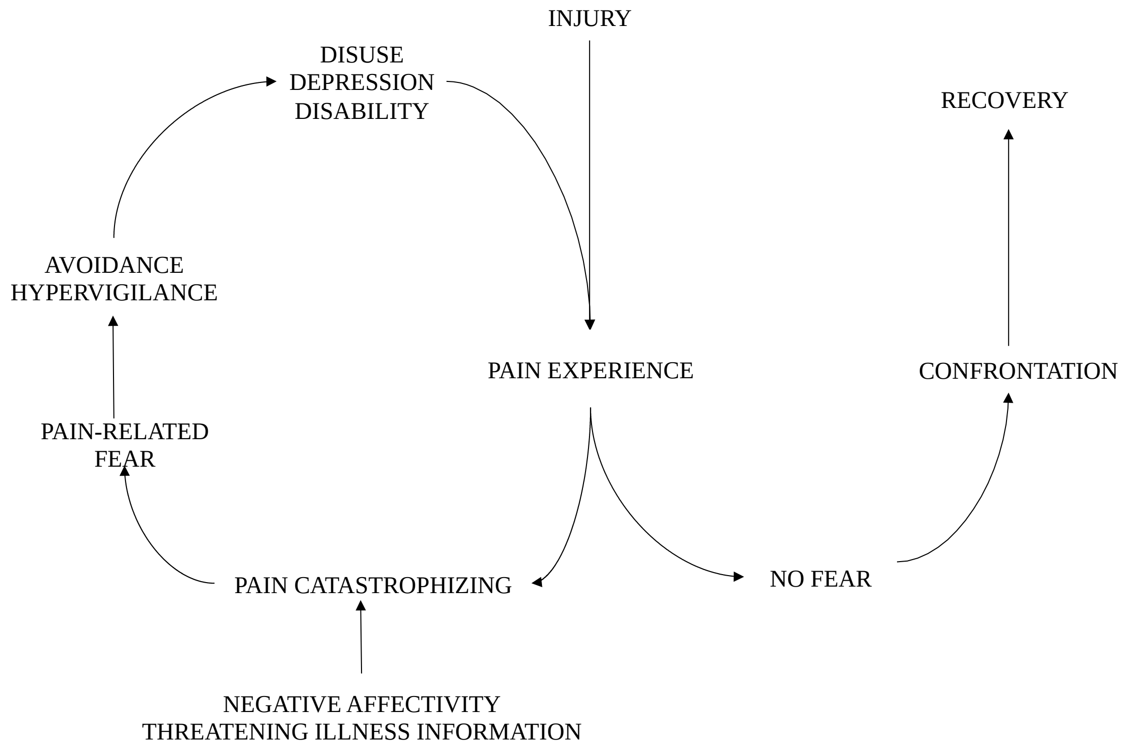

Figure 2.7 Fear-avoidance model (Adapted from Vlaeyen & Linton, 2000)

In contrast to the FAM, an alternative model named Avoidance-Endurance Model (AEM) has been proposed to explain physical activity in chronic pain (Hasenbring & Verbunt, 2010). In the FAM, pain catastrophising and pain-related fear were two important factors leading to physical disuse and disability (Sullivan et al., 2001; Turner & Aaron, 2001; Vlaeyen & Linton, 2000). However, in the AEM, physical overuse or overload is included as an alternative pathway to the development and maintenance of chronic pain (Hasenbring, 2000). Based on the AEM, people with chronic pain use endurance responses in which they suppress their thoughts, distract from pain or minimise their pain by task persistence behaviour and possibly positive mood in spite of severe pain. The AEM suggests that there are three types of response influencing the maintenance of pain and disability (Hasenbring & Verbunt, 2010). First, *Distress endurance response pattern*, refers to people with chronic pain who use thought suppression on the cognitive level, exhibit anxiety/depression on the emotional level and maintain task persistence behaviour in spite of pain on the behavioural level. Second, *Eustress endurance response pattern*, refers to people with chronic pain who ignore pain severity and/or minimise the meaning of pain experiences and maintain task persistence behaviour in spite of pain. This group often has high scores on positive mood in spite of pain. In addition, this group may show maladaptive response pattern by having high fear of pain but maintain task persistence behaviour instead of showing avoidance behaviour. Third, *Adaptive response pattern*, refers to people with chronic pain who shows a high degree of flexibility between fear-avoidance response and endurance response to pain.

Both FAM and AEM address important factors and mechanisms in the development and maintenance of chronic pain and disability. Although these two models are widely recognised and evidence has been found in line with the models assumptions (Vlaeyen & Linton, 2012; Hasenbring & Verbunt, 2010), there are limitations which merit future studies attention. For example, the role of sleep disturbance in the development and maintenance of chronic pain and disability is missing from the models. As discussed in the earlier sections of this chapter (see Section 2.6 and 2.9), sleep disturbance has been associated with a number of negative outcomes in people with chronic pain (e.g., pain severity and intensity, physical inactivity). Therefore, it would be interesting to integrate sleep into the models. For instance in the FAM, sleep can be link to pain experience, disuse, disability, depression and arousal. This in turn may fuel the cycle of poor sleep and physical inactivity.

2.11 Possible roles of psychological variables in predicting physical activity

The previous section contains discussion on models of physical activity in people with chronic pain. The models describe some of the psychological variables such as pain-related fear and pain catastrophising in influencing people in chronic pain to engage in physical activity. The following is a discussion on the possible roles of psychological variables predicting physical activity.

Sallis and Owen (1999) summarised 45 studies (published between 1992 and 1997) pertaining to potential psychological, cognitive and emotional factors that correlate with physical activity among adults. Sallis and Owen (1999) also identified factors that repeatedly documented strong positive association with physical activity (e.g., self-efficacy, motivation), weak or mixed evidence of positive association with physical activity (e.g., personality, psychological health), repeatedly documented lack of association with physical activity (e.g., knowledge of health and exercise), weak or mixed evidence of no association with physical activity (e.g., stress, perceived values of exercise outcomes), repeatedly documented negative association with physical activity (e.g., mood disturbance) and weak or mixed evidence of negative association with physical activity (e.g., lack of time). Smith, Quartana, Okonkwo and Nasir (2009) proposed that multiple psychological variables may interact with sleep to impact on daytime physical activity in people with chronic pain including daily pain and mood disturbance. Potentially, psychological variables during daytime may alter the sleep-pain association, which in turn will influence physical activity as suggested by Tang et al. (2012). Therefore the additional aim of the present thesis was to consider the potential association of psychological variables and physical activity based on cognitive and behavioral factors in chronic pain. Specifically, the study examined the effect of pain, mood, tiredness, fatigue, sleepiness, energy level, body condition, motivation to accomplish tasks, confidence to get things done and management of pain on physical activity.

This chapter began by describing sleep and its function, and discussing that the relationship between sleep and physical activity is likely to be bi-directional in people with chronic pain. It went on to suggest that sleep is a consistent predictor of physical activity the next day at the within-person association. The next chapter explores and refines the concept of sleep quality in people with and without chronic pain.

Chapter 3

Study 1 - Do People With Chronic Pain Judge Their Sleep Differently? A Qualitative Study[2]

3.1 Introduction

Sleep quality is an elusive construct. Despite being a common criterion used to evaluate sleep, there is no authoritative definition of what sleep quality is and how it is being interpreted by the sleeper (Krystal & Edinger, 2008).

Researchers and clinicians have developed different methods to operationalize the construct. Some use multi-component questionnaires that solicit information about sleep patterns, presence of sleep disturbances and use of sleep medications to generate a global index of sleep quality (e.g., Pittsburgh Sleep Quality Index; Buysse et al., 1989). Some ask for an overall rating of sleep quality anchored with generic descriptions of sleep quality such as “very poor quality” or “very good quality”, as seen in sleep diaries (Carney et al., 2012). Additional items measuring “restfulness during sleep” or “refreshness on waking” have also been used to tap into the construct (Akerstedt, Hume, Minors, & Waterhouse, 1994; Wilson, Watson, & Currie, 1998). Some consider the amount of polysomnography-measured slow wave sleep and the level of sleep efficiency as the best physiological correlates of people’s subjective rating of sleep quality (e.g., Keklund & Akerstedt, 1997). These methodological variations reflect the

[2] The contents of this chapter has been published in *Behavioral Sleep Medicine*:
Ramlee, F., Afolalu, E. F., & Tang, N. K. Y. (2016). Do people with chronic pain judge their sleep differently? A qualitative study. *Behavioral Sleep Medicine*, 1-16.

lack of consensus on what sleep quality entails, and although they are accepted methods for indexing sleep quality, they offer limited insights into the parameters people use to define their subjective sleep experience. There is also a tacit assumption that criteria used to judge sleep quality do not vary between individuals or clinical groups.

Two previous studies have specifically explored the subjective meaning of sleep quality in people with and without insomnia. Harvey et al. (2008) used a combination of three approaches (a “speak freely” procedure, a semi-structured interview, and a week’s worth of sleep diary) to identify sleep quality variables that are judged to be most important by insomniacs and compared these with those variables highlighted by normal sleepers. Quantitative analyses of the data revealed that “tiredness on waking and throughout the day” was the most frequently used variable for defining sleep quality by both insomniacs (*n*= 25) and normal sleepers (*n*= 28). Importantly, the authors also found that people with insomnia had a greater number of requirements for judging sleep to be good quality than normal sleepers. Kleinman et al. (2013) conducted focus groups with 28 patients with insomnia at clinical research sites to explore the language people use to describe their sleep experience and sleep quality. The groups were invited to talk about their typical sleep pattern and any night-to-night variations in sleep they had experienced over the past weeks. They were also asked to write down words that describe to them a good night’s sleep, which were then read to the group to generate discussion. Transcripts of the focus groups were qualitatively analyzed for themes. Common adjectives used to describe a good night’s sleep were “restful”, "peaceful", "deep", and "sound", whereas a bad night's sleep was often characterised by both physical and cognitive "restlessness". Consistent with the findings of Harvey et al. (2008), the patients appeared to define the quality of sleep primarily by their feelings on waking. Waking up feeling "tired" and "exhausted" were indicators of poor sleep quality. On the contrary, waking up "in a good mood", feeling "refreshed", "having clear mind", and "motivated" to get things done were indicators of good sleep quality. Transcripts of the focus groups were also reviewed by insomnia diagnosis to uncover potential differences between participants with primary insomnia and those with insomnia comorbid with another psychiatric or medical disorder. However, this review did not identify any clear differences between groups in term of the criteria they use to gauge sleep quality. Taken together, findings from both of these studies suggest non-specific feelings upon waking- rather than objective parameters of sleep are crucial in shaping our judgment of sleep quality. Cognitive-behavioural models of insomnia have explicitly recognised that subjective appraisals of sleep are integral to the pathogenesis of insomnia disorder (Harvey, 2002; Lundh & Broman, 2000; Morin, 1993). Identifying the criteria that people use to judge their sleep quality may provide new inroads for improving patients' sleep experiences and help explain reports of poor sleep quality not accompanied by polysomnography- or actigraphy-measured sleep abnormalities (Harvey & Tang, 2012). This could be of importance in terms of advancing the understanding and treatment of insomnia comorbid with long-term health conditions such as chronic pain.

Sleep disturbance is highly prevalent among people living with painful conditions (Breivik et al., 2006). Poor sleep quality is reported by as many as 99% of patients with fibromyalgia- a long term condition marked by widespread pain in the muscles, tendons, and ligaments (Theadom, Cropley, & Humphrey, 2007), whereas clinical levels of insomnia were found in between 53 and 79% among mixed groups of chronic pain patients seeking treatment from specialist pain clinics (McCracken et al., 2011; Tang, Wright, et al., 2007). Patients often cite pain as a primary reason for sleep disruption and poor sleep quality (Breivik et al., 2006; Morin et al., 1998), although a number of studies have also highlighted the role of cognitive and somatic arousal during the presleep period and the presence of depression and dysfunctional belief about sleep in predicting self-reported sleep quality (Smith & Haythornthwaite, 2004; Tang et al., 2012; Theadom & Cropley, 2008). It remains to be determined what are the key criteria for judging sleep quality among chronic pain patients and to what extent these criteria differ by pain diagnosis.

The present study extended the investigation of sleep quality and definitions to people with chronic pain, with a view to uncovering the common parameters they use to judge their sleep quality. As sleep quality is a subjective judgment, we took an inductive qualitative approach to explore the mental representations of sleep quality in the patients' mind (Pope & Mays, 1995; Thomas, 2003). In depth one-to-one interviews were carried out to provide the data and context for the researchers to interpret and extract meanings. Three groups of participants with widespread musculoskeletal pain, localised musculoskeletal pain and no pain were included to allow for a comparison of sleep quality definitions across diagnostic groups (Egan et al., 2013; Tang et al., 2009).

3.2 Method

3.2.1 Participants

Six participants with fibromyalgia, five participants with back pain, and six healthy individuals were purposively sampled to respectively represent the presence of chronic widespread musculoskeletal pain, chronic localised musculoskeletal pain, and the absence of chronic pain. Participants were recruited through advertisements circulated within local pain patient support groups and flyers displayed across the university campus and the local community.

The inclusion criteria applicable to all participants were (1) aged between 18 and 65 years and (2) English-speaking. An additional inclusion criterion for participants in the fibromyalgia or back pain group was the presence of pain for at least six months, which is in line with the definition of chronic pain (IASP Task Force on Taxanomy, 1994). All participants in the fibromyalgia and back pain groups confirmed that they had received a formal diagnosis of fibromyalgia or back pain from a physician. Exclusion criteria applicable to all groups were: (1) physical disabilities or neurological disorders that prevent them from completing the questionnaire and/or attending the interview (e.g. visual impairment, dementia); (2) severe psychiatric illnesses (e.g., psychosis); (3) sleep disorders that might explain sleep disturbance (e.g., sleep apnea, narcolepsy). Note that participants were not selected based on their sleep complaints, as the researchers were interested in exploring the judgment of sleep quality across the whole spectrum.

Although expert consensus suggests that data saturation for qualitative analysis is generally reached with 12 participants (Guest, Bunce, & Johnson, 2006), the current study interviewed 17 participants in total to provide data for qualitative analysis.

3.2.2 Procedure

Potential participants who responded to the recruitment drive were screened for eligibility over the phone. Those who met the inclusion and exclusion criteria were invited to complete a questionnaire and attend a semi-structured interview. Written informed consent was obtained from each participant prior to the commencement of the interview. The protocol of this qualitative study has been reviewed and approved by the relevant Research Ethics Committee.

Questionnaires were included to characterize the participants, and these comprised a blank body manikin to assess the spread of pain (Lacey, Lewis, Jordan, Jinks, & Sim, 2005), the Brief Pain Inventory to examine pain severity and interference (BPI; Cleeland & Ryan, 1994), Insomnia Severity Index to assess sleep problems (ISI; Bastien et al., 2001), Epworth Sleepiness Scale to measure daytime sleepiness (ESS; Johns, 1991), Multidimensional Fatigue Inventory to assess fatigue (MFI; Smets, Garssen, Bonke, & Haes, 1995), Hospital Anxiety and Depression Scale to assess symptoms of anxiety and depression (HADS; Zigmond & Snaith, 1983), Dysfunctional Beliefs and Attitudes about Sleep Scale (DBAS; Morin, Vallières, & Ivers, 2007) to measure beliefs and attitudes about sleep, and finally, several standard questions about the participants' demographics such as age, sex, BMI, and employment status (see Appendix 4).

The semi-structured interview generated data for the qualitative analysis. Each interview was about 40 minutes long. During the interview, participants were invited to talk in depth about their current sleep patterns and how they make judgment about their sleep quality. To ensure coverage of these topics, five open-ended questions (see Table 3.1) were presented one at a time with supplementary questions from the researcher when a clarification or an elaboration was required. Participants were encouraged to talk freely and allowed to digress as they shared their experiences. This provided the researchers with rich contextual information to better understand the meaning of the speech. At the end of the interview, the participants were fully debriefed (i.e., being reminded of the aims of the research, given an opportunity to ask questions or express concerns about the study, and being asked if they would be agreeable to checking the themes extracted for accuracy at a later stage) and were reimbursed for their travel expenses.

All interviews were audio-recorded and transcribed verbatim by an independent professional transcriber. The transcripts were then reviewed by the interviewer (FR) and another member of the research team (EA) for accuracy.

Table 3.1 *Interview outline*

1.	How would you describe your sleep? Can you tell me about your typical sleep pattern?
2.	How can you tell that you have had a good night's sleep?
3.	How can you tell that you have had a poor night's sleep?
4.	To you, what are the major difference between a good night's sleep and a poor night's sleep?
5	Is there anything that you would like to add about your sleep?

3.2.3 Analysis

The data set for the current study comprised 17 transcripts. A thematic analysis was carried out on all transcripts in accordance with the Braun and Clarke (2006) guidelines. This particular inductive data analysis approach was chosen because it allows the researchers to explore criteria for judging sleep quality with the flexibility to generate unexpected insights from the data. The procedure for thematic analysis is transparent and structured. This minimizes the researchers' bias in summarizing the themes emerged, although some may see this as a disadvantage because it limits the researchers' interpretative power. The qualitative data analysis software, Nvivo10, was used to organize transcripts and to manage the extraction of codes and emerging themes.

There were six key steps in analyzing the data. First, the lead author (FR) familiarized herself with the data by reading and rereading the transcripts. Initial ideas and impression related to the research questions were noted and highlighted. This step allowed the researcher to develop a thorough understanding of the data. Second, initial codes (i.e., brief description of the concepts identified from the data) were constructed as transcripts were being read again. All the coded data were then collated and semantically arranged. Third, potential themes were extracted from the coded data. Fourth, potential themes were carefully reviewed. At this stage, the researcher consulted and discussed with a senior researcher with clinical and research experience in pain and sleep (NT) regarding the precision of the themes and the relevance of the coded data. Differences in opinions were resolved by discussion. Fifth, to ensure our interpretation did not deviate from original meaning of the data, the extracted themes and codes were sent to a subsample of the participants (*n*= 7) for validation. Feedbacks from the participants were incorporated into the final stage of analysis, which led to the naming of each theme. The coded data were arranged into a table in accordance with the themes they supported. When generating the themes, the researchers not only paid attention to words used by the participants, but also the context in which the participants articulated themselves. Finally, the researchers compared and contrasted the themes across fibromyalgia, back pain and the healthy groups. This final step allowed the researchers to examine whether people with chronic pain judged their sleep quality differently from those without chronic pain, and whether people with fibromyalgia evaluated their sleep quality differently from people with back pain.

The reporting of the current study closely adheres to the consolidated criteria for reporting qualitative research (COREQ) to promote comprehensiveness and transparency (Tong, Sainsbury, & Craig, 2007).

3.3 Results

Participant characteristics

Table 3.2 presents the demographics and clinical characteristics of the participants by group. Nine (52%) of the 17 participants were male, eight (48%) were female. Age of the participants ranged from 19 to 64 years old, with a mean age of 42.1 years (SD= 15.5) and a mean BMI of 27.9 (SD= 5.89). Of the 17 participants, 7 (41%) were in full-time employment, 7 (35%) were on sick leave, medically retired, retired or not working, and the remaining 3 (18%) were studying full-time.

Although no statistical analysis was performed on the questionnaire scores given the small sample size and the qualitative nature of the current study, the overall pattern of data appeared to suggest a stepwise progression in the spread of pain across the diagnostic group (healthy controls < back pain < fibromyalgia). The same pattern of stepwise progression by diagnostic grouping was also found for pain severity, pain interference, insomnia severity, dysfunctional beliefs and attitudes about sleep, fatigue, anxiety and depression. The only exception was daytime sleepiness, whereby the scores were identical between the back pain and the health control groups, although both groups reported a lower level of daytime sleepiness than the fibromyalgia group. Only the fibromyalgia group had a mean score above the clinical threshold for ISI (23.1), ESS (10.3), and HADS (anxiety= 12.5; depression= 12.3). These scores indicated severe clinical insomnia, significant daytime sleepiness, and probable presence of anxiety and mood disorders in the fibromyalgia group.

Table 3.2 *Participant characteristics by group*

	Fibromyalgia (*n*= 6)	Back Pain (*n*= 5)	Healthy pain-free (*n*= 6)
<u>Demographics</u>			
Sex			
Male	3	3	3
Female	3	2	3
Age (in years)	49 (11.6)	35.2 (19.2)	41 (15.3)
BMI	27.8 (5.4)	32.4 (6.2)	24.2 (3.6)
Employment status			
Full-time employment	1	3	3
On sick leave/ medically retired/ retired/ not working	5	-	2
Full-time studying	-	2	1
<u>Clinical characteristics</u>			
Body manikins (number of area shaded)	24.5 (9.9)	4.2 (3.1)	N/A
BPI- Present Pain Severity	6.1 (0.5)	3.8 (0.9)	0.5 (1.0)
BPI- Pain Interference	8.3 (0.9)	3.8 (1.6)	0.5 (0.8)
ISI	23.1 (3.7)	14.4 (4.2)	8.3 (3.3)
ESS	10.3 (7.4)	6 (4.8)	6 (3.5)
DBAS-16	7.23 (1.4)	4.3 (1.8)	3.2 (1.3)
MFI	88.8 (11.8)	56 (10.4)	47.5 (18.9)
HADS(A)	12.5 (2.7)	7.6 (1.8)	5 (2.7)
HADS(D)	12.3 (2.3)	5.6 (2.8)	4 (2.5)

Notes. Mean values are presented with standard deviations in parentheses unless otherwise specified. BMI= Body mass index. BPI= Brief Pain Inventory. ISI= Insomnia Severity Index. ESS= Epworth Sleepiness Scale. DBAS-16= Dysfunctional Beliefs and Attitudes about Sleep. MFI= Multidimensional Fatigue Inventory. HADS(A)= Hospital Anxiety and Depression Scale (Anxiety). HADS(D)= Hospital Anxiety and Depression Scale (Depression).

Thematic Analysis

Four salient themes emerged as criteria used by the participants to judge their sleep quality (See Figure 3.1). Each of these themes is presented below with direct quotes from the participants.

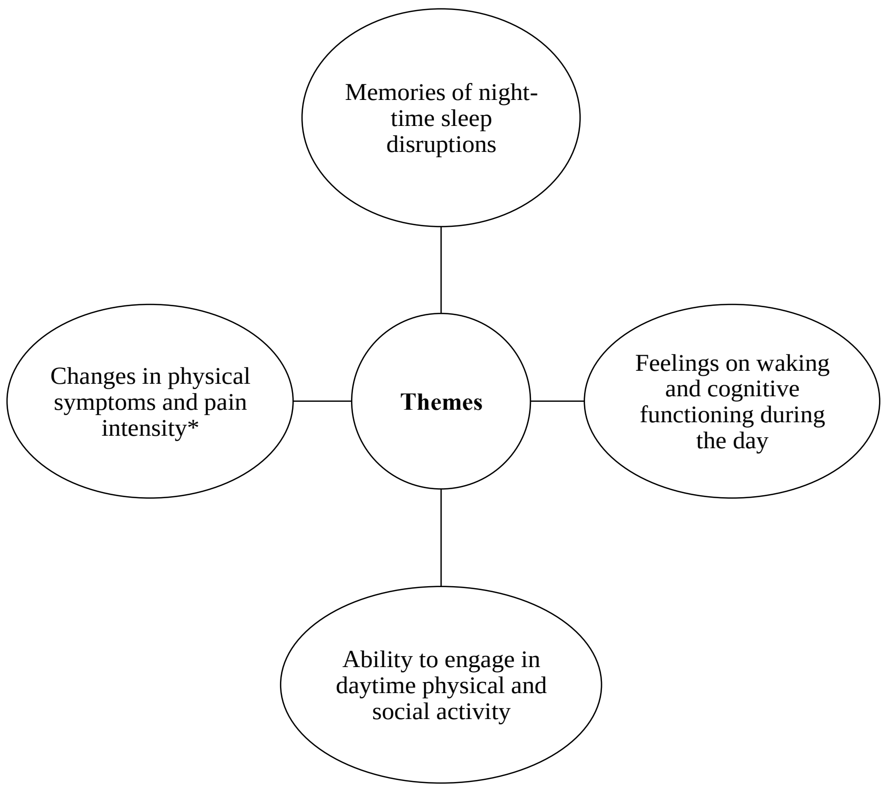

Figure 3.1 Themes emerged as criteria for judging sleep. *Introception of pain intensity only applied to the fibromyalgia and back pain groups.

Theme 1: *Memories of night-time sleep disruptions*

There was a clear consensus that the participants judged their sleep quality based on their remembered ability to “switch off” and stay asleep. Awakenings in the middle of the nights were cited as indicators of poor sleep quality; the more memories of wakefulness, the stronger the feeling of having had a bad night’s sleep. A good night’s sleep was typically characterized by the general absence of interruptions to sleep and/or memory of noise or any non-sleep activities, as illustrated by the quotes that follow:

> “It’s that sensation of really I have switched off, I am not aware of anything. That you know, those three hours where maybe the following day my husband said to me, ‘Oh did you hear the thunderstorm last night?’ ‘No,’ because it happened on those three hours and I didn’t hear anything. I didn’t hear the thunderstorm, I didn’t notice the light, nothing, and that is for me a proper sleep. When I’m aware of everything else I’m not, and I get up noticing that I have not slept properly” (Fibromyalgia, Female, 49).

> “A good night’s sleep is that it’s not interrupted it will have little to no interruption. I mean if I do wake up it will only be the once and it will be for five minutes, when I am just sort of like hear a noise and I just roll over” (Back Pain, Female, 19).

> “There are some nights when I am woken up several times for whatever reason, you know and it can be a combination of factors I might need to go to the loo, or one of the boys might wake up, or the dogs, or George [pseudonym] who makes equally as much noise and I suppose if I felt that my sleep was very disturbed because of that, or because of a combination of those factors, I would feel I had a poor night’s sleep” (Healthy, Female, 45).

Theme 2: *Feelings on waking and cognitive functioning during the day*

Feeling refreshed on waking emerged as a key criterion of good quality sleep. Although it was unclear what exactly was meant by “feeling refreshed”, the participants noted that on days when they felt refreshed by sleep they would be motivated to get up and be ready to start the day without any hesitation. In contrast, a poor night sleep was generally associated with a struggle to get up in the morning, tiredness on waking, and the desire to stay in bed and get some more sleep. The feeling of being refreshed by sleep appeared to be linked to the ability to overcome the sleep inertia upon transitioning from sleep to wakefulness.

> "I know when I've had a good night's sleep because I would wake in the morning feeling refreshed" (Fibromyalgia, Male, 41).

> "A bad night's sleep I feel bad the next day and a good night's sleep I feel refreshed, ready to go, on the ball" (Back Pain, Male, 64)

> "It's [a good night's sleep] waking up fresh, get up easy, get stuck straight into whatever tasks I have to do, whatever I'm going to do, as opposed to having to will myself to climb out of bed and get organized" (Healthy, Male, 63).

The participants also retrospectively judged their sleep quality based on their daytime task performance. They noted that a night of poor sleep was typically followed by a day of forgetfulness and mind-wandering. They cited that they would have difficulty in finding words, struggle to stay focused on tasks, and be slow in thinking and retrieving information. Whereas on a day when they were able to function well and think clearly, they would typically consider themselves having had a good night's sleep. There appears to be an assumed direct link between sleep and daytime cognitive performance.

> "I will be thinking and, and trying to explain stuff to you, but my mind will just go completely blank. That gets worse on certain days, obviously with less sleep, but on other days I can sort of string together" (Fibromyalgia, Male, 41)

> "I feel more alert. I do quite a physical job, but it, it's very mental as well, there's a lot of measurements and stuff I have to take, and the days will fly and everything's clear, and if I haven't had a good night's sleep the run of the mill jobs are quite problematic I have to really concentrate on stuff that normally I could just fly through" (Back Pain, Male, 45).

> "If I've had a bad night's sleep I might have word finding difficulties, so, because I teach, and so I'm standing there and I'm trying to explain something and I feel slow selecting the words that I need to be able to explain" (Healthy, Female, 53).

Theme 3: *Ability to engage in daytime physical and social activity*

Another index commonly used by the participants to gauge their sleep quality was their ability to fully engage in physical and social activities during the day. The participants cited that, following a poor night's sleep they tended to find themselves avoiding social engagements. Lacking energy, they would cancel appointments to give themselves an opportunity to catch up on sleep. Daytime fatigue and social withdrawal during the day were perceived to be indicators of poor quality sleep.

> "Having a bit more energy say after a good night sleep I've got a bit more energy to be able to go a whole day and to do things, after a bad night's sleep fatigue will hit me at say half 3 in the afternoon eventually, plug's pulled and I fall asleep standing up more or less" (Fibromyalgia, Male, 34).

> "I say when I'm tired or if I've felt like I've had very little quality sleep, I can become quite withdrawn, I don't want to be involved, I don't engage, I don't want to make conversation, so that is very much the opposite of who I am. I mean I'm quite an enthusiastic person, quite an open person, and will engage with, I will happily talk to anybody. I'm working in a job where we interact with people, like staff and customers, and to then have that day where, and other people notice and they will say to me, 'Are you okay?' and, because it is very noticeable difference" (Back Pain, Female, 28).

> "After a good night's sleep, I'm more likely to do exercise because my day will be more organized. So with a good night's sleep I'm likely to be more active"(Healthy, Female, 53).

Theme 4: *Changes in physical symptoms and pain intensity*

The participants paid attention to their bodily sensations when they made judgment of their sleep quality. Physical symptoms (e.g., headache, migraine and sore eyes) and unexpected loss of appetite were used to infer poor sleep quality.

> "After a bad night's sleep I usually wake up maybe with a headache and my eyes quite tired or sore" (Healthy, Female, 25).

> "If I have a good night's sleep I feel that I don't really have like a migraine, and when I haven't had much sleep I have a feeling of a headache, of a migraine and also I don't have as much like tension in my neck and shoulders because I do find when I don't have much energy, I do have quite a lot of tension in my neck and shoulders so that's how I sort of know" (Back Pain, Female, 19)

> "Sometimes when I've had a bad night my appetite goes as well. I have to eat something to take my medication but I will force myself to eat a bit of toast or something you know just so I've got something in my tummy to take the tablets" (Fibromyalgia, Female, 45).

Additionally, for participants with fibromyalgia or back pain, they factored in their current pain when judging sleep quality. These participants perceived an increase in pain as an indicator of poor night's sleep and showed appreciation of the self-perpetuating cycle of pain and poor sleep. They believed that a poor night's sleep would aggravate pain and fuel the risk of re-injury. When describing the pain, the participants used words such as "tight" and "swelling". The choice of words appears to suggest that both musculoskeletal and inflammatory mechanisms are involved in the reciprocal link of sleep and pain.

> "After a bad night's sleep, my muscles and my joints can be really quite painful and tight cause I haven't rested them properly" (Fibromyalgia, Female, 45).

> "I feel constantly in pain, which obviously when I don't get enough sleep will aggravate that, and then because I've aggravated pain I don't get enough sleep. So I am on a vicious cycle, I can't sleep properly because of the pain, and I can't, because I am not sleeping, I then get in more pain" (Fibromyalgia, Male, 41).

> "If I've had a bad night and it's painful it's obviously because of the swelling, because it will be like swelling in the bottom of the spine, so I have to be careful all day in case I aggravate it even more, so, and, and it plays on my mind because it's there all day, so I am generally aware of it more and I have to be so much more careful in case I injure it" (Back Pain, Male, 45).

3.4 Discussion

Across participants with and without chronic pain, four key parameters emerged to be key criteria for judging sleep quality. Namely, these criteria were "*memories of night-time sleep disruptions*", "*feelings on waking and cognitive functioning during the day*", "*ability to engage in daytime physical and social activity*" and "*changes in physical symptoms and pain intensity*". Introception of pain intensity, however, only applied to participants from the fibromyalgia and back pain groups. Whereas previous studies have predominantly focused on night-time parameters as correlates of sleep quality (Akerstedt et al., 1994; Keklund & Akerstedt, 1997), the current findings suggest that sleep quality is also influenced by daytime parameters. This may seem counterintuitive, but not so much when considering that daytime dysfunction is core to the experience of insomnia and it is usually one of the main reasons why individuals seek treatment for their sleep problems (Kyle, Espie, & Morgan, 2010).

Theme 1: Memories of night-time sleep disruptions

To participants in the current study, being able to sleep through the night is a fundamental criterion for a good night's sleep. Indeed, multiple studies have shown that subjective sleep quality was correlated with sleep efficiency, wake after sleep onset (WASO) and number of wake bouts in the night (Bastien et al., 2003; Diaz-Piedra et al., 2015; Feige et al., 2008; Keklund & Akerstedt, 1997; O'Donoghue et al., 2009). It is, however, interesting to note that under normal circumstances most people do not have access to sleep measuring technologies. As such, sleep quality judgments rest heavily on the absence of memories of awakenings and the non-specific recollection that the mind has "switched off". These underline the importance of successful formation of mesograde amnesia during sleep in shaping subjective judgment of sleep quality (Perlis, Giles, Mendelson, Bootzin, & Wyatt, 1997; Perlis, Smith, Orff, Andrews, & Giles, 2001).

Several factors may play a role in shaping the sleeper's memory of wakefulness. First, the duration and timing of the awakening. It has been suggested that if an awakening marks only a brief period of arousal as short as 16 seconds on the PSG recording (Perlis et al., 1997), then there is a good chance that the awakening would be forgotten and that it would not disrupt the natural mesograde amnesia of sleep. However, it should be mentioned that experimental induction of brief arousals (<3 seconds of minimum duration of alpha activity) in healthy volunteers during the sleep onset period has been associated with subjective reports of poor sleep quality and longer sleep onset latency that is not reflected in the PSG recording (Smith & Trinder, 2000). Second, certain stages of sleep such as N1 and REM can be easily experienced as wake, particularly in people with insomnia (Mercer, Bootzin, & Lack, 2002). Although the exact mechanism underpinning this phenomenon is not clear, the presence of excessive cognitive (e.g., worries) and physiological (e.g., pain) arousal may play a role in interpreting sleep as wakefulness, by blurring the distinction between wake and sleep during sleep onset period (Bonnet & Arand, 1992; Mercer et al., 2002). Third, memory of sleep can be influenced by the current mental state of the sleepers. Hartmann, Carney, Lachowski and Edinger (2015) examined the correlation between a retrospective measure of sleep quality based on the PSQI (i.e., for the last month) and a prospective measure of sleep quality derived from two weeks of sleep diary in insomnia patients with and without a comorbid psychiatric diagnosis. They found that the correlation between the two sleep quality measures was moderated by mental health status, with a significantly weaker association being found in insomnia patients with a comorbid psychiatric diagnosis. These patients also had a higher PSQI score than those without a psychiatric diagnosis, but this difference disappeared when the effect of anxiety was partialled out. The authors therefore suggested that retrospective sleep quality judgment is, to some extent, negatively biased by the mood states of psychiatric patients. Finally, attentional bias towards sleep-related threat is a cognitive characteristic of people with insomnia (Taylor, Espie & White, 2003; Semler & Harvey, 2007; Spiegelhalder et al., 2010). Selective attention to and/or active monitoring of signs and cues of sleeplessness may also contribute to participants' memory of wakefulness by increasing the load of information processing and further elevating the levels of cognitive and emotional arousal. Understanding these factors that influence memory of wakefulness may help explain the often-observed discrepancy between the objectively estimated sleep and the sleeper's subjective sleep experience (Harvey & Tang, 2012).

Theme 2: Feelings on waking and cognitive functioning during the day

Both participants with and without chronic pain evaluated their sleep quality using information and cues that occur after sleep, on the subsequent day. In other words, people inferred their sleep quality based on how they felt on waking and what they could and could not do during the day. It is important to note that the retrospective nature of the sleep quality judgment applies to not only the context of completing a questionnaire asking about overall sleep quality, but also on a daily basis when people are asked to give a sleep quality rating in the morning after each night of sleep. Non-specific feelings on waking appeared to be an important indicator of sleep quality. Participants used generic terms such as "unrefreshed", "tiredness", and "fatigue" to describe the effect of a poor night's sleep, highlighting an implicit assumption that one should be able to function well during the day when their sleep is restorative.

Theme 3: Ability to engage in daytime physical and social activity

Following from the previous theme, sleep quality judgment is also defined by the participant's daytime physical and social activity. The assumed link between sleep and next day activity apparently is bi-directional. In fact, participants even went as far as describing a tendency to do more after having had a good night's sleep and do less after having had a bad night's sleep. This is consistent with experimental findings reported by Semler and Harvey (2005), who gave pre-determined sleep quality feedback to 22 adults with primary insomnia who believed their sleep was being monitored and spontaneously analyzed. The feedback was either positive (good quality sleep condition) or negative (poor quality sleep condition) and was randomly given to the participants according to their assigned experimental condition, remotely via a pager immediately on waking. Over the 3 days of experiment, the authors found that the participants engaged in less physical activity (e.g., cancelling appointments, taking a daytime nap) on days following the receipt of negative feedback relative to positive feedback days. A similar association between perceived sleep quality and subsequent physical activity has also been observed among chronic pain patients in a daily process study conducted by Tang and Sanborn (2014), who asked 119 chronic pain patients with insomnia to monitor their sleep and physical activity in their natural living and sleeping environment for a week. In addition to wearing an actiwatch throughout the whole study, participants completed a daily electronic diary three times a day to provide subjective ratings of their sleep quality, pain and mood upon waking, in the first half of the day, and in the second half of the day. Fitting multilevel models on these time-specific data, the authors discovered that sleep quality rating of the night before was a significant determinant of the next day's physical activity as measured with actigraphy. Pain and mood ratings in the morning, however, did not predict subsequent levels of physical activity. These findings highlight a potential role of sleep quality judgment in the regulation of physical activity in general and within the context of chronic pain. Physical inactivity is a common issue of chronic pain (Hasenbring & Verbunt, 2010; Huijnen, Verbunt, Peters, & Seelen, 2010; McLoughlin et al., 2011). It has been postulated in the fear-avoidance model (FAM) as a form of avoidance behavior fuelled by pain catastrophizing and the consequent fear of pain and re-injury (Asmundson, Norton, & Vlaeyen, 2004; Vlaeyen & Linton, 2000). For chronic pain patients with comorbid insomnia, subjective perception of poor sleep quality may well be an additional factor that promotes more focused attention on pain, negative thinking, and activity avoidance (Affleck et al., 1996; Asmundson, Norton & Vlaeyen, 2004; Vlaeyen & Linton, 2000). There may be value applying cognitive-behavioral therapy for insomnia (CBT-I) as an adjunct treatment for improving sleep and daytime functioning in people with chronic pain (Jungquist et al., 2010; Tang, Goodchild, & Salkovskis, 2012), especially therapy with a cognitive component that addresses subjective perception/evaluation of sleep quality (Harvey, Sharpley, Ree, Stinson, & Clark, 2007).

Theme 4: Changes in physical symptoms and pain intensity

Physical changes and bodily discomfort (e.g., loss of appetite, muscle tension) were reported as signs of poor sleep quality across all participants with and without pain. These findings are consistent with those of Harvey et al. (2008), who found that body sensations on waking and throughout the day was mentioned by participants as a parameter of sleep quality judgment. Different from pain-free individuals, participants with chronic pain tended to focus their attention on subtle changes in pain spread and pain intensity and they used their pain experience to infer how well they have slept the night before (e.g., “The pain has been worse than usual this morning. I must have had a poor night’s sleep”). Chronic pain participants explicitly described their sleep and pain experience as a vicious cycle, with poor sleep magnifying pain and worse pain resulting in further trouble sleeping. This type of pain-related sleep belief, if held rigidly and inflexibly, may play a role in furthering sleep disturbance and pain interference (Afolalu et al., 2016).

Strengths, limitations, and implications

The current study is the first to uncover common parameters of sleep quality across individuals with and without a pain condition. The findings from this study have provided new insights into judgment of sleep quality from the sleepers’ perspective and generated a number of testable hypotheses about the reciprocal link between perceived sleep quality and daytime functioning. However, generalizability of the results needs confirmation from future empirical studies with larger samples. The qualitative nature of the study also means that the researchers play an active role in analyzing and extracting themes from the data. Interpretations of the data/themes may have been influenced by the researchers’ personal beliefs and biases, although we should note that several measures were taken to minimize the researchers' biases, such as consulting a senior researcher and sending the codes and extracted themes to a subsample of participants for validation. We closely followed the Braun and Clarke (2006) guideline at each step of the analysis and provided example of multiple quotes for each theme to ensure our interpretation of themes was fair and transparent.

Findings emerged from the present study have a couple of interesting implications. Theoretically, if judgment of sleep quality is affected by not only memories of last night's sleep but also feelings on waking and functioning during the day, sleep quality ratings may vary throughout the day depending on the timing of assessment. Daily process studies with multiple assessments of sleep quality will help clarify to what extent sleep quality changes throughout the day and identify the contextual factors associated with these changes. Future assessments of day-to-day sleep quality should consider factoring in the effect of time. Standardizing the timing of sleep diary completion, for example, may help maximize comparisons of sleep quality judgment between days, even within the same individual (Carney et al., 2012). Clinically, it may be worthwhile educating the patients about the influence of their sleep quality judgment on their subsequent daytime activities, as well as the reverse inference of sleep quality based on mood, physical sensations, cognitive clarity, and activities performed during the day. For patients with chronic pain, their use of pain as an indicator of poor sleep appears to be stemming from the belief that sleep and pain interact in a vicious cycle, with poor sleep magnifying pain and worse pain resulting in further trouble sleeping. Loosening up this belief and eliminating pain from the sleep quality judgment will allow the patient to embrace the treating of insomnia despite ongoing pain (Afolalu et al., 2016; Tang et al., 2012). For patients with subjective insomnia not accompanied by objective sleep deficits, promoting engagement in physical and social activities during the day may represent a new avenue for improving sleep quality.

Conclusion

In conclusion, the present study extends our knowledge of the way people with and without chronic pain judge their sleep quality. Sleep quality is not solely determined by night-time parameters but also by daytime processes through retrospective judgment. Particularly, people with chronic pain view pain experience and sleep quality as two linked entities that influence their ability to engage in daytime activities as planned. To the sleeper, using indirect indicators to infer sleep quality is only natural as they do not have access to sleep assessment technology and the experience of sleep is marked by darkness, loss of consciousness and amnesia. The current findings highlight the potential benefits of targeting daytime symptoms in attempts to improve sleep quality. A possible extension of FAM specifying the role of perceived sleep quality in influencing people's decision to engage in daytime physical and social activity may also offer a more comprehensive framework for understanding of chronic pain. As a follow-up from this study, the next chapter quantitatively examines sleep quality parameters in good and poor sleepers.

Chapter 4

Study 2 - What Sways People's Judgement Of Sleep Quality? A Quantitative Choice-Making Study With Good And Poor Sleepers[3]

4.1 Introduction

Sleep quality is an important indicator of health and wellbeing in both healthy and clinical populations (Cappuccio, D'Elia, Strazzullo, & Miller, 2010; Cappuccio, Cooper, D'Elia, Strazzullo, & Miller, 2011; Patel & Hu, 2008; Pilcher, Ginter, & Sadowsky, 1997). In the context of sleep treatment, it is also an important patient-reported outcome used to reflect treatment progress or to determine treatment success (Edinger, Wohlgemuth, Krystal, & Rice, 2005; Garland et al., 2014; Martinez et al., 2014; Wells, Li, Maxwell, Maclean, & Tugwell, 2008). However, sleep quality is an elusive construct that is difficult to measure. Thus far, there is no consensus on the definition of sleep quality and what it consists of (Krystal & Edinger, 2008). Whilst it is understood that numerous factors related or unrelated to sleep can affect people's judgement of sleep quality (Hartmann et al., 2015; Mystakidou et al., 2007), little is known about their relative importance and how they interact with each other to sway sleep quality judgement.

Current measurements of sleep quality range from single-item rating scales to multi-item questionnaires. These various instruments and measurement approaches

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[3] The contents of this chapter has been published in SLEEP:
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reflect their respective ideas of what sleep quality is all about. In terms of utility, each has their strengths but also their limitations. Single item sleep quality rating scales (e.g., "how would you rate the quality of your sleep?") are often used in daily sleep diaries (Carney et al., 2012) and large-scale epidemiological studies (Foley, Ancoli-Israel, Britz, & Walsh, 2004). They provide a quick and yet undefined measurement of sleep quality since definitions of sleep quality do differ between individuals. In fact, one question often raised by patients/participants regarding this item on the sleep diary is ironically "what do you mean by sleep quality?". In receipt of such question, the clinician's/researcher's spontaneous interpretation of sleep quality could have a strong influence over the patient's/participant's assessment of sleep quality. However, the simplicity of these single-item rating scales is attractive, as they are easy to use in clinical settings as well as research studies that require repeated measurements of daily sleep quality over a period of time. Multi-item questionnaires such as the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) and Medical Outcomes Study (MOS) sleep scale (Hays, Martin, Sesti, & Spritzer, 2005) are well-validated measures of sleep quality and commonly used in research and clinical settings. In these instruments, sleep quality is represented by a composite score encompassing various aspects of (i) sleep experience during the night (e.g., sleep latency, sleep duration), (ii) reports of sleep disturbances (e.g., waking up in the middle of the night, having to get up and use the bathroom, coughing or snoring loudly, having pain), (iii) subjective evaluation of sleep quality (e.g., good or bad, quiet or restless, feeling rested upon waking or not), (iv) the bedroom environment (e.g., sleep disturbance from a bed partner or roommate, too hot or too cold), and (v) sleep-related behaviour during the day (e.g., trouble staying awake, having to take sleep medication, having to take naps). These multi-item measures are comprehensive, but sleep quality is pre-defined for the respondents and may have been conflated with symptoms of sleep disorders (e.g., sleep apnoea). Implicitly, these measures also assume that the respondents would put equal emphasis on each pre-defined factor while forming their overall judgement of sleep quality, which is at odds with the suggestion that different individuals tend to have different interpretations of what sleep quality is (Yi, Shin, & Shin, 2006).

A number of previous studies have attempted to identify physiological correlates of sleep quality. These physiological indices include both micro and macro measures of sleep architecture, such as cyclic alternating pattern rate (Krystal & Edinger, 2008; Rizzi et al., 2004), slow-wave sleep (Westerlund, Lagerros, Kecklund, Axelsson, & Åkerstedt, 2014), percentage of REM (Milross et al., 2002), greater delta NREM EEG activity (Krystal, Edinger, Wohlgemuth, & Marsh, 2002), sleep continuity/efficiency (Akerstedt, Hume, Minors, & Waterhouse, 1994), number of awakenings at night (Diaz-Piedra et al., 2015), and total sleep time (Landis et al., 2003). Whilst these objective indices provide information about the possible physiological underpinning of the sleep experience, they do not correlate well with subjective ratings of sleep quality (Edinger et al., 2000; Lichstein et al., 2006) and there are conflicting findings as to which objective measure is central to the subjective judgement of sleep quality. For example, Landis et al. (2003) found that objective total sleep time was strongly correlated with sleep quality (r= .635, p< .01), whereas Westerlund at al. (2014) demonstrated that the amount of time spent in stage 2 sleep, not objective total sleep time, was the only significant predictor of sleep quality (β = -.07, $p < .01$).

More recently, there is a renewed interest in investigating the definition of sleep quality from the sleeper's perspective using qualitative approaches. This qualitative approach acknowledges sleep as a private, subjective experience and has proved to be a particularly fruitful method for collecting in-depth data from individuals based on their interpretations of what happened during, as well as before and after, sleep. Using focus group discussion, Kleinman et al. (2013) explored the language 28 insomnia patients used to describe their sleep experience. Discussions were also generated based on descriptions written by the patients, who were asked to write down words that described to them a "good night's sleep". Some of the phrases used to describe a good night's sleep were "restful", "peaceful", "sound sleep", and waking up feeling "refreshed", "energetic" and "motivated", whereas a poor night's sleep was typically characterised by physical and cognitive "restlessness" as well as waking up feeling "tired" and "exhausted". Meanwhile, Harvey et al. (2008) asked participants with insomnia and normal sleepers to talk freely for 3 minutes about the characteristics of a night when they experienced good sleep quality and then for another 3 minutes about poor sleep quality. These authors combined this speak freely procedure with a semi-structured sleep quality interview and a week's worth of sleep diary to examine the subjective meaning of sleep quality. From their mixed-methods analysis, they found that – to the participants – sleep quality was most commonly defined by "tiredness on waking and throughout the day", "feeling rested and restored on waking", and "number of awakenings experienced in the night". Interestingly, in their analysis of the meaning of sleep quality they found that both people with insomnia and normal sleepers had similar definitions of sleep quality, although people with insomnia tended to use more criteria to judge a good night's sleep than the normal sleepers. Taken together, findings from Kleinman et al. (2013) and Harvey et al. (2008) reveal that people use multiple criteria to judge their sleep quality, and that the factors affecting the judgement of sleep quality can occur during the night as well as beyond the typical nighttime sleep period. There appears to be some systematic differences between good and poor sleepers in the way in which they judge the quality of a good night's sleep and poor night's sleep, but further investigation is required to confirm these main effects.

The present study aimed to extend our understanding of the factors influencing our sleep quality judgement, by examining the relative weights they carry in the sleep quality judging process. We were also interested in examining the possible interaction between the parameters of sleep quality extracted from different time periods, between different types of sleeper, and between different types of judgement. To do so, we conceptualised the subjective report of sleep quality as a decision-making process. By that, we mean, when people make judgement of their sleep quality, they will inevitably have to process and integrate their memories of their sleep experience during the night, their feelings on waking, and their assumed impact of sleep quality on their functioning the next day. People will have to weigh up the relative importance of the various factors/criteria that make up their good or poor night's sleep. For example, in our research with people with chronic pain and comorbid insomnia, we found that patients considered pain and discomfort in the morning and how much they can physically do during the day as the most important indicators of sleep quality of the night before (Ramlee et al., 2016).

Once we had conceptualised the sleep quality judgement as a decision-making process, we saw that the challenge of finding the factors that led to a good and poor night's sleep was similar to the challenge of product design and marketing. Product managers need to determine how consumers weigh various factors, such as screen size and resolution, when evaluating the quality of a television. Whilst we are interested in sleep quality instead of television quality, and the factors that can influence sleep instead of screen size and resolution, these problems are essentially the same. Thus we can use methodology commonly deployed to address this question: choice-based conjoint analysis. In choice-based conjoint analysis, individuals are presented with a series of choices between options with different features, and regression models are used to infer how the features are weighted (Green & Rao, 1971; Rao, 2014). Choice-based conjoint analysis represents a novel, and yet potentially more ecologically valid, methodology for uncovering the important parameters that determine people's sleep quality judgement.

4.2 Methods

4.2.1 Design

In our choice-based conjoint analysis, instead of evaluating each sleep parameter individually, we simulated the real-life decision-making process by presenting our participants with two concrete descriptions of sleep/wake scenarios comprising a combination of sleep quality parameters highlighted in the literature. After repeating this choice exercise over a sufficient number of trials, we used regression to quantitatively estimate the relative importance of all included parameters of sleep quality and examined if these parameters interact with each other.

A quantitative choice-making study was thus conducted with 100 young adults. In the first part of the study, the participants were asked to complete a set of questionnaires, which contained items asking about the participant's demographics, typical sleep pattern and insomnia severity in the past three months. These data were used to characterise the participants. The second part of the study was an experimental session, during which the participants were asked to read and choose between two scenarios to answer the question "*Which describes a better night of sleep?*" in half of the trials, or "*Which describes a worse night of sleep?*" in the remaining half of the trials. Each scenario described a subjective experience of sleep, in the first person narrative, stringing together 17 possible determinants of sleep quality that we had identified from our literature review. These determinants are referred to below as "sleep quality parameters" or "parameters of sleep quality judgement". Each participant answered 48 questions (i.e., 48 trials) and the data from these trials were used to evaluate the relative importance of each sleep quality parameter.

The protocol of the study received full ethical approval from Humanities and Social Sciences Research Ethics Committee (Reference number: 44/13-14), University of Warwick. All participants were paid an honorarium for their participation.

4.2.2 Participants

Participants of this study were aged between 18 and 30 years and were recruited from a university-wide subject panel. The study was conducted with young adults to minimise the effect of comorbid psychiatric and medical symptoms and the use of medications on decision-making (Hartmann et al., 2015). Participants were included in the study if they were (1) aged 18 to 65 at the time of the study and (2) English-speaking. Participants were allocated to the "good sleeper" group if they scored 7 or below on the Insomnia Severity Index (ISI; Bastien et al., 2001) indicating no clinically significant insomnia. Participants were included in the "poor sleeper" group if they scored 8 or above on the ISI and had been experiencing one or more of the following symptoms for at least three nights a week for at least three months, despite having an adequate opportunity to sleep: (1) difficulty initiating sleep (taking longer than 30 minutes to fall asleep), (2) difficulty staying asleep (frequent midnight awakenings), (3) early morning awakening with an inability to return to sleep, (4) daytime functioning impairment (e.g., poor concentration, excessive sleepiness). These insomnia symptoms were assessed using a self-report checklist and these group allocation criteria were set in line with the DSM-5 diagnostic criteria for insomnia disorder, for assessing the presence of insomnia symptoms (American Psychiatric Association, 2013).

Figure 4.1 shows the recruitment flow diagram. Of the 111 individuals who responded to the recruitment advert, 50 participants met the criteria of good sleeper, 50 participants met the criteria of poor sleeper, and the remaining individuals did not show up to the experimental session (*n*= 11). Seven participants were excluded from the analysis on the basis of an average trial completion time of less than 20 seconds, which was an extremely fast completion time that suggested non-compliance to the task instruction. This cut-off completion time was determined based on the pilot study (see Materials section in Methods). A further 6 participants were excluded due to the methodological necessity to remove the first participants of each data chain (see the Analysis section for an explanation).

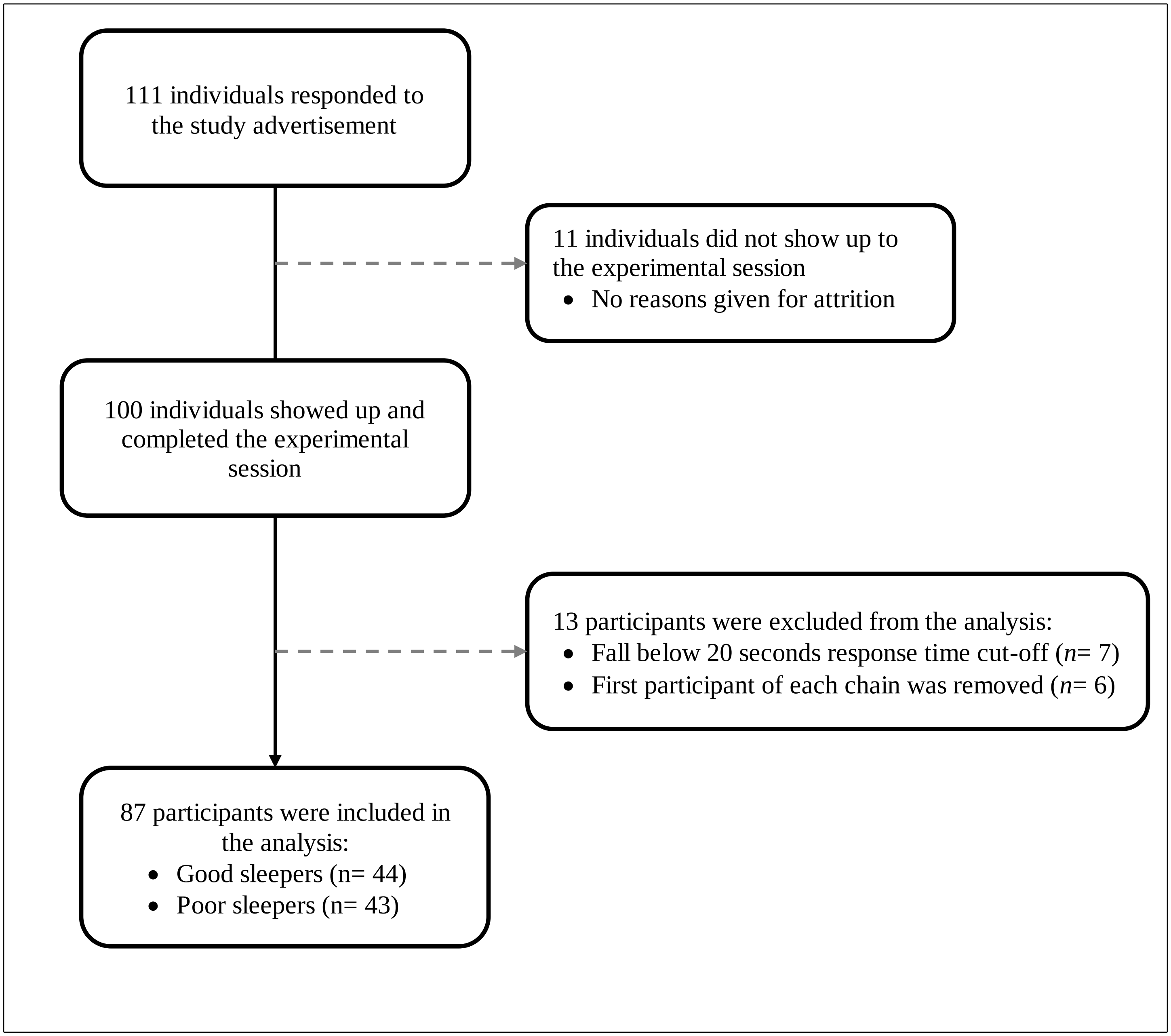

Figure 4.1 Flow diagram of participant recruitment

4.2.3 Procedure

Potential participants who responded to the recruitment advert completed a screening/ demographic questionnaire and attended an experimental session. Written informed consent was obtained from the participants before commencing the experimental session, which took place in small groups of 3 to 4 participants in a lab with multiple computers partitioned into stations. The lab was sound attenuated with central air conditioning and lighting control. Each participant was assigned to a computer at some distance from the others to minimise distraction and response contamination.

The participants were asked to read and imagine themselves being the person experiencing 48 pairs of scenarios. They read a pair of scenarios in each trial and were asked to choose one scenario from each pair that represents a night of better (or worse) sleep quality, depending on the question that they were presented. To avoid misunderstanding what was being expected from the tasks, in addition to verbal explanations the participants were given detailed written instructions on the computer screen. The exact instructions on the computer screen read as follows:

> "*On the following pages, you will be shown two scenarios per page, each inside its own box. Click on a box to read the scenario inside. You are allowed to read each scenario a maximum of two times.*
>
> *The two scenarios can be quite similar to each other. Please read each carefully and importantly imagine yourself being the person who experienced the scenario described.*
>
> *You can only read one scenario at a time so try to get an overall impression of a scenario as you read it. When you have established a clear picture of the scenarios in your mind, pick the scenario that you feel answers the question about sleep quality.*
>
> *Use a select button to indicate your choice (the buttons will be available after you have read both scenarios). There is no time limitation, but please respond as quickly and accurately as possible*."

The number of trial for each participant was set to 48 due to concerns of task fatigue and the practical time limits of reading speed, which does not allow for the comparison of the huge number of possible stories (3 options $^{16 \text{parameters}}$ x 5 options $^{1 \text{ parameter}}$ = 215,233,605 stories). Instead, we aimed to present a subset of stories that were similar enough to be easily comparable, and also to focus on stories that would lead to the most extreme ratings of sleep quality. Previous work in conjoint analysis has used genetic algorithms for the task, as genetic algorithms work by presenting a large set of candidate scenarios, from which the participant select those that will 'survive'. The surviving scenarios are mutated to produce new options, and the process repeats until a good set of candidate options has 'evolved' (Balakrishnan & Jacob, 1996). However, because participants will likely become confused when choosing amongst a large number of scenarios, we used a simpler algorithm with the same properties, Markov Chain Monte Carlo with People (MCMCP; Sanborn, Griffiths, & Shiffrin, 2010; see details in *Markov Chain Monte Carlo with People* of this section), which accomplishes the same goal by presenting choices between pair of scenarios. Similar to a genetic algorithm, after the participant has made a choice, the chosen scenario is 'mutated' to produce a new scenario, and the participant then decides whether their previous choice or the new scenario is better. Scenarios were mutated by changing a random number of parameters, which was drawn from a truncated geometric distribution with a mean of number of parameter changes of 4.6. Each parameter was equally likely to be changed, and all new options for a parameter were equally likely. Figure 4.2 graphically depicts the scenario mutation process and the corresponding actions required from the participant at each stage.

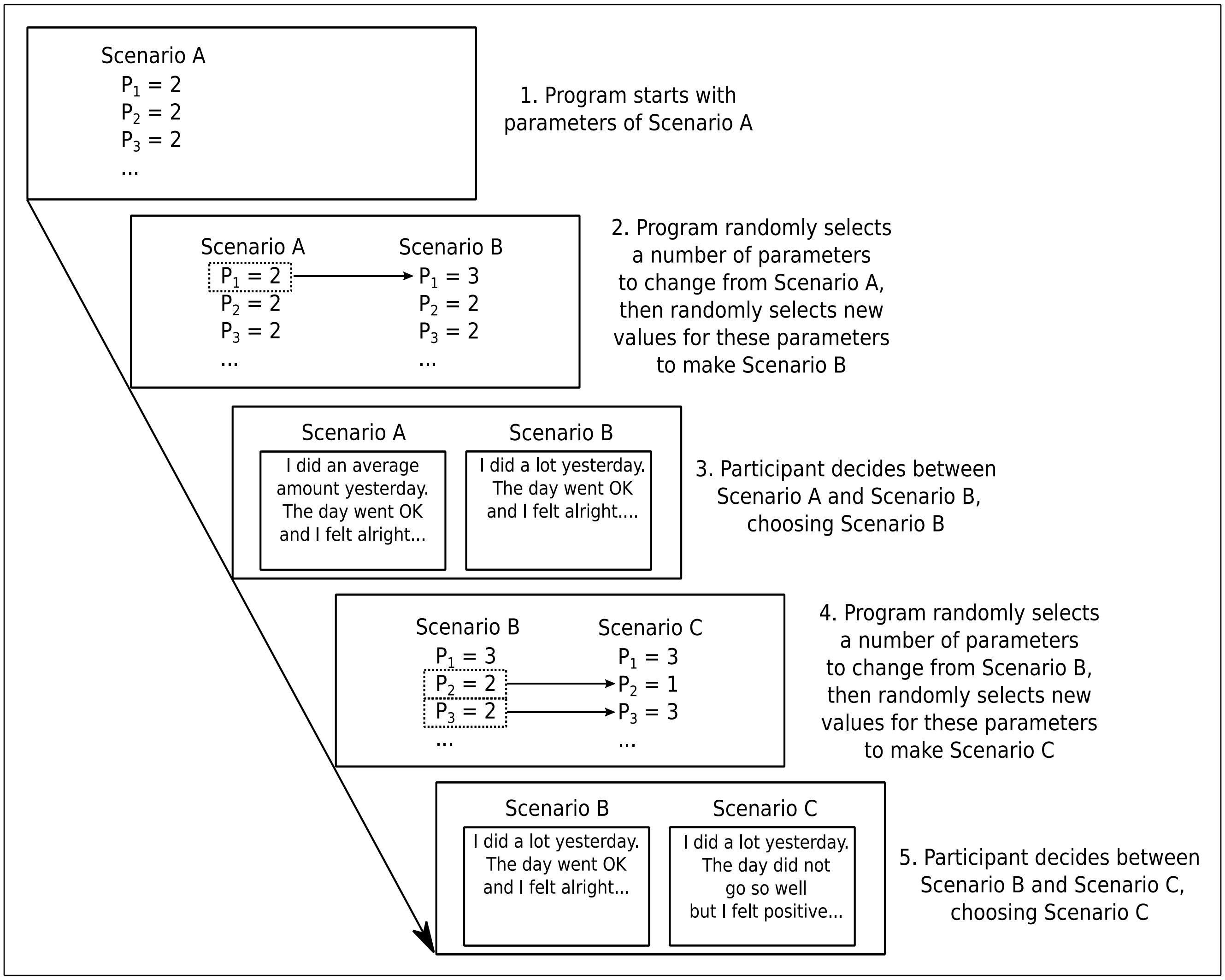

Figure 4.2 An example of how the MCMCP algorithm mutates the scenarios in response to a participant's choices. The notation $P_x = Y$ refers to parameter x in Table 1, which is set to level Y. For example $P_1 = 2$ means that the first parameter, “amount of activity”, is set to the second level, “an average amount”.

The sequential nature of MCMCP means that the scenarios are chained together, with the previous choice influencing what is presented on the next trial. Because we did not wish to make the sequential nature of the trials obvious, we created multiple independent chains which were interleaved together.

The 48 trials were presented in 4 chains of 12 trials; two chains asking participants "*Which describes a better night of sleep?*" and another two chains asking "*Which describes a worse night of sleep?*". Also, the chains carried over from one participant to the next: this enhanced the power of the analysis at the cost of assuming no individual differences in how participants weighted the factors (Martin, Griffiths & Sanborn, 2012). Finally, to improve the speed of data collection we set up multiple groups of chain that could be run in the same testing session: three good sleeper and three poor sleeper groups (see Figure 4.3).

Each testing session was approximately 50-min long. Participants were given a 5-min indoor break after 24 trials to counteract any task-related fatigue. However, no stimulant use (coffee, tea, energy drinks or cigarettes) was allowed during the break. All participants completed the task and were paid an honorarium at the end of the testing session.

Good sleeper (*n*= 50)	**Chain 1** (12 trials) Better night's sleep	**Chain 2** (12 trials) Better night's sleep	**Chain 5** (12 trials) Better night's sleep	**Chain 6** (12 trials) Better night's sleep	**Chain 9** (12 trials) Better night's sleep	**Chain 10** (12 trials) Better night's sleep
	Chain 3 (12 trials) Worse night's sleep	**Chain 4** (12 trials) Worse night's sleep	**Chain 7** (12 trials) Worse night's sleep	**Chain 8** (12 trials) Worse night's sleep	**Chain 11** (12 trials) Worse night's sleep	**Chain 12** (12 trials) Worse night's sleep

Poor sleeper (*n*= 50)	**Chain 1** (12 trials) Better night's sleep	**Chain 2** (12 trials) Better night's sleep	**Chain 5** (12 trials) Better night's sleep	**Chain 6** (12 trials) Better night's sleep	**Chain 9** (12 trials) Better night's sleep	**Chain 10** (12 trials) Better night's sleep
	Chain 3 (12 trials) Worse night's sleep	**Chain 4** (12 trials) Worse night's sleep	**Chain 7** (12 trials) Worse night's sleep	**Chain 8** (12 trials) Worse night's sleep	**Chain 11** (12 trials) Worse night's sleep	**Chain 12** (12 trials) Worse night's sleep

Figure 4.3 Multiple chains of each group*

*Notes: To break down the concept of chaining, we created the chains because we wanted to enable the algorithm to sample the different extreme scenarios (i.e., better vs. worse night's sleep). This allows us to answer the question whether question type makes a difference in people's judgement of sleep quality.

Each participant was only required to do 48 trials, which was not enough data to allow us to analyze participants individually. Therefore we chained participants together so that the last scenario chosen by one participant was used as one of the first choices for the next participant who was in that chain.

Given the sequential nature of the sampling, we also wanted to make the mutation process (see Figure 4.2) less obvious to the participants. By creating more chains, we could interleave them to masquerade the sequential nature of the sampling and make the choice-making task more varied and interesting to the participants to counteract cognitive fatigue. Finally, we created multiple groups of chains (good sleeper group: chains 1-4; chains 5-8; chains 9-12; poor sleeper group: chains 1-4; chains 5-8; chains 9-12). This was purely to help us speed up the data collection process, so we could run multiple participants at a time.

The removal of the data from the first participant of each chain was necessary because of the nature of the MCMCP sampling procedure, which has to start with particular arbitrary scenarios that neither represent a very good or a very poor night's sleep. However, as participants along a chain made choices sequentially, the scenarios mutated towards the prototypical representations of good or poor night's sleep (see Figure 4.2), allowing them to make choices between variations of these scenarios. That is why it is conventional to remove the "burn-in trials", so choices made at the beginning of the MCMCP sampling procedure do not affect the overall results.

Markov Chain Monte Carlo with People

Ideally we would like to know the sleep quality of each of the stories, but because there is a very large number of possible stories (3 options$^{16\text{parameters}}$ x 5 options$^{1\text{ parameter}}$ = 215,233,605 stories), collecting choices for each pair of stories is not feasible. Instead, we applied the Markov chain Monte Carlo algorithm (Neal, 1993) developed in computer science and statistics to solve the similar problem of summarising complex probability distributions. The MCMC algorithm takes samples from the complex distribution to provide an approximation of the distribution.

Our data were collected using the Markov Chain Monte Carlo with People method (Sanborn et al., 2010), which draws samples from people's mental representations and is an application of the MCMC algorithm. Starting in an initial "state" (in our case, a scenario), the algorithm proceeds by first making a "proposal", which is a randomly modified version of the initial state. With this state and proposal, in a fully automated computer program the MCMC algorithm decides whether the next state in the chain should be either the current state or the proposal, given that the probability of choosing the proposal is a ratio of the probabilities of the state and proposal [e.g., $p(x_{proposal})/(p(x_{state}) + p(x_{proposal}))$]. A long series of these sequential choices are made, which forms the "chain" of states. This resulting chain of states is a series of samples from the complex probability distribution.

MCMCP turns this fully automated algorithm into one in which people make decisions, instead of the machine. This is applied to explore people's mental representations of subjective concepts, such as sleep quality. The computer executes most of the procedure as before, randomly proposing new states and keeping track of the chain. However, instead of letting the computer decide whether to transition to a new state, a participant makes the decision of whether to stay with the current state or transition to the proposal.

In our case, participants do this by viewing a pair of stories (i.e. the state and the proposal) and choosing which scenario better answers a question about sleep quality. The chosen scenario is the new state of the chain. Because people make these forced-choice decisions probabilistically [e.g., $m(x_{proposal})/(m(x_{state}) + m(x_{proposal}))]$, where $m(x)$ is the match of scenario x to the question), we can use their decisions as a replacement for the decision function in the MCMC algorithm. The choices participants make in a long sequence of chained decisions will appear with probability equal to their relative match to the question: the best scenario should appear the most often, the second-best the second most often etc.

However in MCMCP, like in MCMC, care must be taken to discard the initial few states of the chain because they are heavily influenced by what the experimenter chose for the initial state (i.e., not the participant's mental representation). The data discarded is called the "burn-in" (discussed in the Results section). Also, the states that are produced are auto-correlated, the effective sample size is smaller than the actual sample size. Hence, while the counts of the chosen stories are an estimate of people's mental representation of sleep quality, we chose to analyze the individual choices that participants made in a logistic regression because these choices can be treated as independent, which gives us greater statistical power.

4.2.4 Materials

As shown in Table 4.1, each sleep scenario contained 17 adjustable parameters. These parameters were chosen following a review of relevant studies that examined the factors that influence people's judgement of sleep quality (Akerstedt et al., 1994; Carey, Moul, & Pilkonis, 2005; Harvey et al., 2008; Kleinman et al., 2013; Webb, Bonnet, & Blume, 1976; Westerlund et al., 2014; Yi et al., 2006). The selection of parameters was also informed by themes that emerged from a recent qualitative study conducted by our group, in which we explored the criteria people use to judge their sleep quality (Ramlee et al., 2016). In this study, we found that people by and large rely on their (1) memories of nighttime sleep disruptions, (2) feelings on waking and cognitive functioning during the day, (3) ability to engage in daytime physical and social activity and (4) changes in physical symptoms as key criteria for evaluating their sleep quality. Accordingly, the chosen parameters were not restricted to the sleep period, but included factors that spanned from the day before the sleep period to the day after. The selection of parameters was led by the last author (NT; who has clinical and research experience working with individuals with and without insomnia), in consultation with the first author (FR) regarding the content and with advice from the second author (AS) regarding the feasibility and programmability of the scenarios and computing resources required. Disagreements were resolved by team discussion. Parameters retained after discussion were then tested in a pilot study with 64 young adults, which helped us to identify programming errors, readability of the resultant scenarios, speed of reading, compliance to the instructions, and efficiency in generating distinguishable scenarios for analysis (i.e., number of burn-in trials).

The 17 final parameters were weaved together with predetermined pronouns and conjunctive words/phrases to generate a first person account of sleep experience.

Each parameter had 3 options, with the exception of "*wake after sleep onset*" (*WASO*) for which 5 options were provided. The combination of parameters and options allows us to generate 215,233,605 possible scenarios.

Table 4.1 *Options for each parameter of sleep quality*

Parameters	Option 1	Option 2	Option 3	Option 4	Option 5
Day before					
Amount of activity	I did little	I did an average amount	I did a lot		
Day went well?	Did not go so well	Went OK	Went well		
Mood	I felt rubbish	I felt alright	I felt positive		
Pre-sleep					
Readiness to sleep	I did not feel sleepy at all	I felt moderately sleepy	I felt very sleepy		
Cognitive arousal	My mind was racing with thoughts	My mind was wandering with thoughts	My mind was blank		
Physiological arousal	I felt very uncomfortable	I felt not so uncomfortable	I felt very uncomfortable		
During sleep					
Sleep onset latency	It took me a long time	It took me a short while	It took me no time		
Wake after sleep onset	I woke up in the middle of the night and was unable to fall back to sleep	I woke up in the middle of the night and was eventually able to fall back to sleep	I woke a number of times but only briefly	I woke once or twice but only briefly	I slept through the night
Total sleep time	I think I slept for 9.5 hours	I think I slept for 7.5 hours	I think I slept for 5.5 hours		
Dream	I remember having many dreams	I remember I dreamt	I don’t remember any dreams		
Upon waking					
Feeling refreshed	I felt unrefreshed	I felt somewhat refreshed	I felt refreshed		
Motivated to get up	I felt unmotivated	I felt somewhat motivated	I felt motivated		
Day after					
Alertness	I felt drowsy	I felt tired	I felt alert		
Thinking	My head felt cloudy	My head was reasonably clear	My head was clear		
Mood	My mood was bad	My mood was average	My mood was good		
Sociability	I was antisocial	I was somewhat sociable	I was sociable		
Physical activity	I was sluggish	I was reasonably active	I was active		

Figure 4.4 presents a screen-shot of two example scenarios from which the participants had to select one of the scenarios to answer the question, "*Which describes a worse night of sleep?*". Only one scenario was visible at a time and the scenario could not be viewed again after it had been viewed twice. Viewing was restricted in this way in order to encourage the participants to make a sleep quality judgement based on their imagination of the scenario as a whole, instead of making their judgement based on comparisons of individual parameters between scenarios. We never asked participants to report these holistic impressions, but instead just asked them to use these internal impressions to make a choice between the two scenarios. We observed the choices, and used a logistic regression analysis to determine how each parameter was weighted when making these choices.

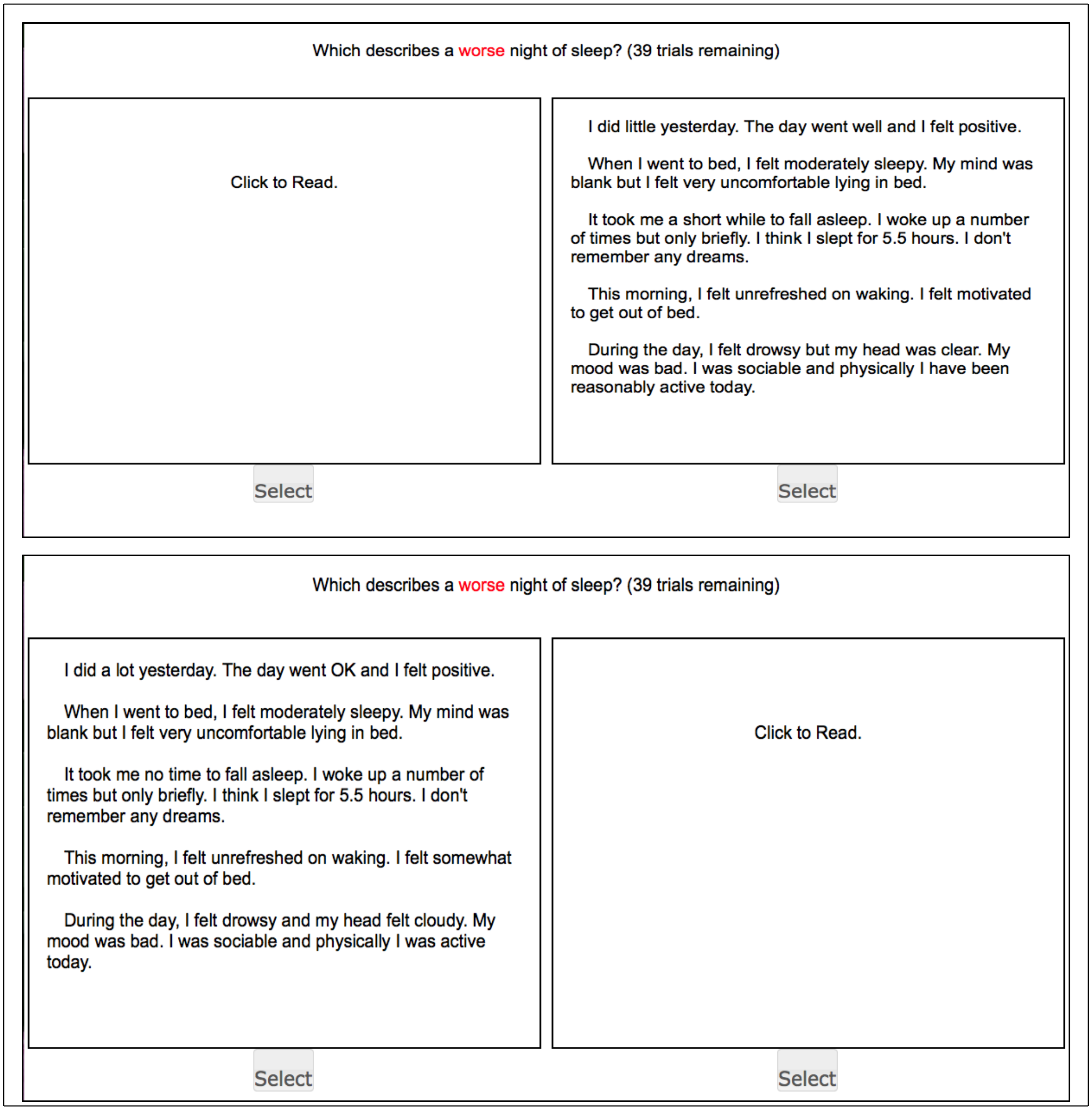

Figure 4.4 Examples of scenarios that were presented to a participant. **The upper panel** was the first scenario that appeared on screen; **The lower panel** was the second scenario appeared on screen; **Scenario**: each set of sleep scenarios presented in the box comprised 17 adjustable sleep quality parameters; "**Click to Read**": participant used this button when s/he ready to read the scenario; "**Select**": participant used this button to indicate his/her choice; **Types of question**: Which describes a worse night of sleep?; **Trials**: Each participant had 48 trials to complete, e.g. "39 trials remaining" in the above example means the participant had finished 9 trials and had 39 trials remaining.

4.2.5 Analysis

Data was analysed using the statistical software R (http://www.r-project.org/). Descriptive statistics were used to describe participants' characteristics. Means and standard deviations were presented to describe continuous variables, whilst frequencies and percentages were reported for categorical variables. Independent sample t-test and chi-square statistics were used to describe the differences in characteristics between the good and poor sleeper groups.

Chains were first analysed to determine the best number of trials to discard as burn-in trials (i.e., choices that had not yet 'evolved' into good or poor sleep quality scenarios). Analyses using the Brooks and Gelman (1998) convergence diagnostic indicated that it was best to remove very few trials, so only the first participant was removed from each chain. As a result, six participants were excluded from the analysis in addition to seven participants who were excluded because they fell below the 20 seconds cut-off response time during the trials.

The effect of each parameter on choices made was examined using logistic regression. The logistic regression model was performed on all of the data including both questions ("*Which describes a better night sleep?*"; *"Which describes a worse night sleep?*") and both good and poor sleepers. The data were drawn from 87 participants who completed 48 trials each, which produced 4,176 choices.

The dependent variable was which scenario was judged to be a better night's sleep for both types of question asked. The parameters found in the logistic regression are interpretable as log odds: they quantify how much more or less likely a participant would choose a scenario if a particular option is included.

The logistic regression model included main effects of each parameter as well as a variety of interactions. Specifically, the terms of the model are:

1) The 17 parameters listed in Table 4.1 (e.g., *mood*, *sleep onset latency* [*SOL*], *physical activity*)
2) Two-way parameter interactions. These were the interactions between the four parameters *during sleep* (*SOL*, *wake after sleep onset* [*WASO*], *total sleep time* [*TST*], and *dream*) crossed with the seven *upon waking* and the *day after* parameters (feeling *refreshed, motivated to get up, alertness, thinking, mood, sociability,* and *physical activity*), yielding 28 terms out of the possible 272 pairwise interactions between parameters. These interactions were selected because better experiences the next day were expected to mitigate a poorer night's sleep (Harvey, 2002; Lundh & Broman, 2000).
3) Two-way interactions between parameters and types of sleeper (e.g., *SOL* and good sleepers), which added an additional 17 terms.
4) Two-way interactions between parameters and types of question (e.g., *alertness* and *Which describes a better night of sleep?*), which added an additional 17 terms.

Statistical tests were performed by comparing the full model to restricted models that did not include a parameter or any higher-level interactions with that parameter. For example, when assessing whether *WASO* was a significant determinant of sleep quality judgement, the full logistic regression model was compared to a restricted model without the *WASO* term or any interactions that included *WASO*. This approach to jointly test whether a parameter has an effect by comparing a full model to a model with both the interaction and the main effect removed has been proposed for use in genetics by researchers who are interested in whether a gene has either a main effect or an interaction with the environment, but are unsure which one it will be (Kraft, Yen, Stram, Morrison, & Gauderman, 2007). Nested models were compared using likelihood ratio tests, where the difference in deviances of the models is compared against a chi-squared distribution with degrees of freedom equal to the difference in number of parameters of the two models. The type I error rate was set to 0.01 to control for multiple comparisons.

4.3 Results

Participant characteristics

Table 4.2 presents the participants' characteristics by group. The mean age of the 87 participants included in the analysis, 60% female, was 22.5 years. There were significant differences between good and poor sleeper groups on the ISI and other sleep variables. The good sleeper group scored lower on the ISI, awoke less often, had shorter WASO, took less time to fall asleep and had greater TST than the poor sleeper group. There was no difference between the good and poor sleeper groups in terms of their age, BMI, sex, ethnicity, and first language.

Table 4.2 *Participant's sleep and demographic characteristics*

		Group total	Good sleeper	Poor sleeper	Comparison between good and poor sleeper
		n= 87	*n*= 44	*n*= 43	
Demographic variables					
Age (years)		22.5 (2.6)	22.6 (2.6)	22.3 (2.6)	t(85)= .68
BMI		21.7 (3.3)	21.7 (2.8)	21.8 (3.8)	t(76.96)= -.14
Sex	Male	35	20	15	χ^2 (1, N= 87)= 3.3
	Female	52	24	28	
Ethnic Origins	White	27	16	11	χ^2 (1, N= 87)= 93.3
	White Irish	1	1	0	
	Asian British: Chinese	30	14	16	
	Asian British: Indian	10	7	3	
	Asian British: Asian other	15	4	11	
	Black or Black British	1	1	0	
	British mixed	1	0	1	
	Other	2	1	1	
First language	English	38	20	18	χ^2 (1, N= 87)= 1.4
	Other	49	24	25	
Sleep variables					
	ISI	8 (5.3)	3.61 (2.1)	12.5 (3.5)	t(68.35)= -14.43***
	Typical SOL (mins)	24.9 (24)	15 (14)	35.12(27)	t(62.35)= -4.24***
	Typical WAKE (mins)	1	1	2	t(56.64)= -3.52**
	Typical WASO (mins)	6.5 (10.4)	3.2 (6.4)	9.9 (12.5)	t(62.23)= -3.2***
	Typical TST (mins)	457 (77.1)	483 (78.7)	430 (66.5)	t(85)= 3.36***

Notes. Mean values are presented with standard deviations in parentheses, except for sex, ethnicity and first language where the number of count (frequency) is presented. BMI= Body mass index. ISI= Insomnia Severity Index. SOL= Sleep onset latency. WAKE= Number of wake after sleep onset. WASO= Wake after sleep onset. TST= Total sleep time. *p<0.05; **p<0.01; ***p<0.001;

Effects of individual parameters on sleep quality judgement

The multiple parameters of sleep quality covered the experience of the *day before* sleep, during the *pre-sleep* period, *during sleep*, *upon waking*, and the *day after* (see Figure 4.5). The parameters that occurred during the *day before* sleep did not have a significant impact on the participants' choices (*amount of activity*: p= 0.38; *day went well?*: p= 0.93; *mood*: p= 0.19). Of the *pre-sleep* parameters, only *physiological arousal* (p< 0.001) had a significant impact on the participants' choices (*readiness to sleep*: p= 0.06; *cognitive arousal*: p= 0.09). Of the *sleep* parameters, *SOL* (p< 0.001), *WASO* (p< 0.001) and *TST* (p< 0.001) had a significant impact, whereas memory of *dream* (p= 0.08) did not have a significant effect on the participants' choices. Both of the *upon waking* parameters had a significant impact (*feeling refreshed*: p< 0.001; *motivated to get up*: p< 0.001). All of the *day after* parameters had a significant impact (*alertness*: p= 0.01; *thinking*: p< 0.001; *mood*: p< 0.001; *sociability*: p < 0.001; *physical activity*: p < 0.001).

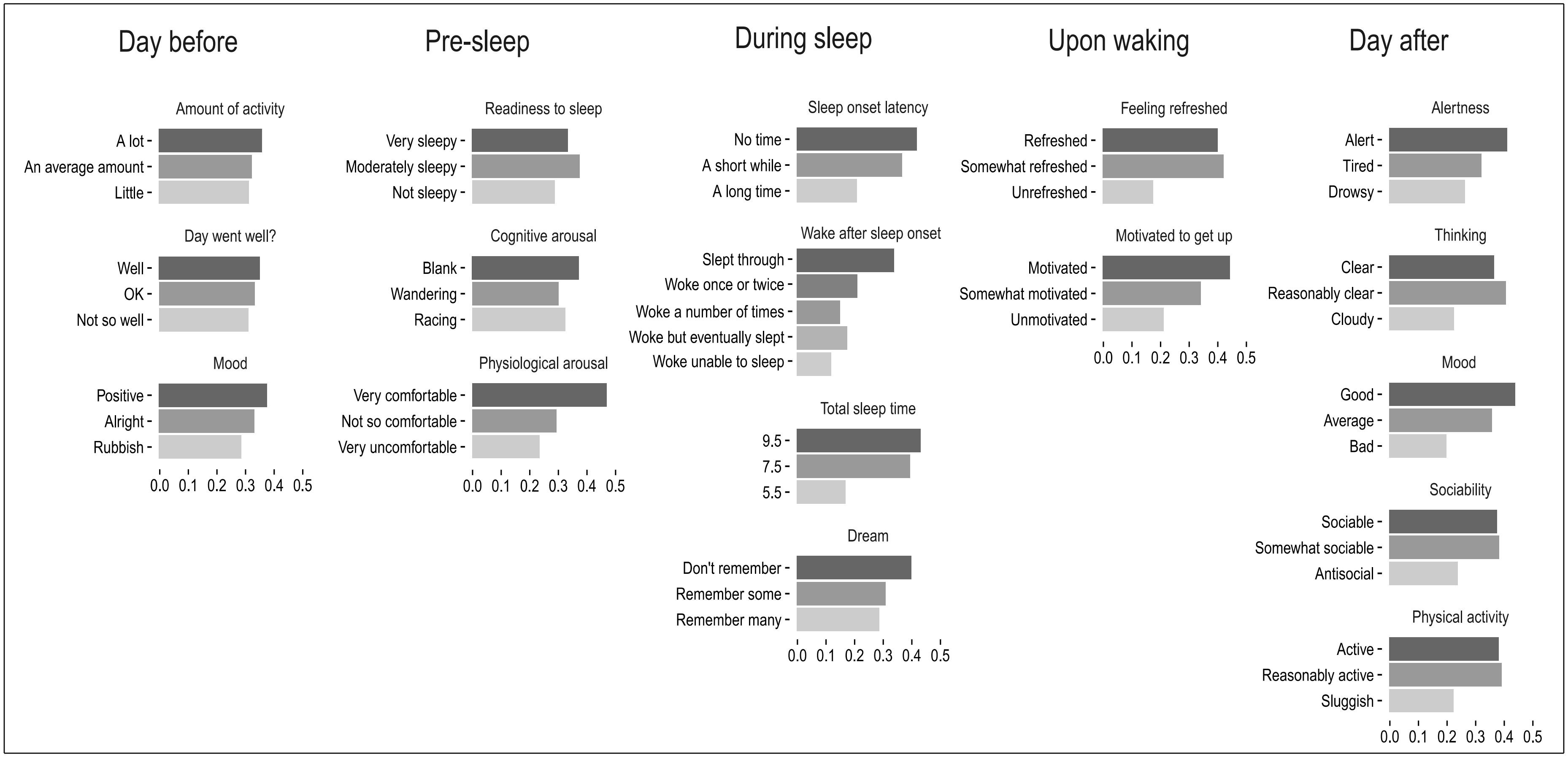

Figure 4.5 Descriptions of a good night's sleep. Seventeen adjustable sleep quality parameters (bar plots) and their options (individual bars) are organised by five time periods. The relative bar lengths of two options represent the relative probability of choosing a scenario that contains those options, e.g., because the bar for "No time" for *sleep onset latency* is twice as long as the bar for "A long time", then a scenario that contains "No time" is twice as likely to be chosen as a scenario that contains "A long time", all other parameters being equal.

An analysis was run to compare the importance of different individual parameters and different time periods in explaining the participants' choices. This analysis was performed by fitting the choice data with single factor logistic regression models (e.g., a model using only the parameter *amount of activity*) and comparing how well each model fit the data. We performed this comparison using Bayesian Information Criterion (BIC), which is a method for trading off goodness of fit against model complexity (Schwarz, 1978). Better (i.e., lower) BIC values are given to models that explain the data well without too many parameters. Using this measure, as shown in Table 4.3, the most important individual parameter of sleep quality, was *TST*, followed by *feeling refreshed* (*upon waking*), then *mood* (*day after*) and then *motivated to get up* (*day after*). We also performed the same analysis on time period by fitting the choice data with logistic regression models that included all parameters within a single time period (e.g., the model for *upon waking* had both the *motivated to get up* and *feeling refreshed* parameters). As shown in Table 4.3, the most important time period was *during sleep*, followed by *upon waking*, then *day after*, then *pre-sleep* and finally the parameters that occurred *day before* sleep were least important.

Table 4.3 *Individual parameters and time periods log likelihood and BIC values*

	Log likelihood	BIC values
Parameters		
Total sleep time	-2822	5668
Feeling refreshed	-2824	5674
Mood (Day after)	-2845	5714
Motivated to get up	-2851	5727
Wake after sleep onset	-2846	5733
Sleep onset latency	-2858	5741
Physiological arousal	-2863	5751
Physical activity (Day after)	-2865	5755
Thinking (Day after)	-2868	5762
Alertness (Day after)	-2875	5775
Sociability (Day after)	-2877	5780
Mood (Day before)	-2880	5784
Dream	-2885	5795
Readiness to sleep	-2886	5797
Cognitive arousal	-2888	5802
Amount of activity (Day before)	-2889	5803
Day went well? (Day before)	-2891	5808
Time period		
During sleep	-2740	5573
Upon Waking	-2788	5617
Day after	-2766	5624
Pre-sleep period	-2854	5766
Day before	-2876	5810

Notes. The log likelihood (larger is better) and BIC values (smaller is better) combine goodness of fit with a penalty for complexity. Parameters and time periods are ordered from most to least important (i.e., by BIC values).

Based on the log odds estimated for each significant parameter option, the "best-preferred scenario" for a better night's sleep was as follows, with words in bold/italic indicating the adjustable option of the eleven significant parameters:

> "I felt ***very comfortable*** lying in bed. It took me ***no time*** to fall asleep. I ***slept through the night***. I think I slept for ***9.5*** *hours*. This morning, I felt ***somewhat refreshed*** on waking. I felt ***motivated*** to get out of bed. During the day, I felt ***alert*** and my head was ***reasonably clear***. My mood was ***good***. I was ***somewhat sociable*** and physically I was ***reasonably active*** today".

Interaction between parameters of sleep quality

We examined the interactions between the four parameters *during sleep* (*SOL*, *WASO*, *TST*, and *dream*) crossed with seven *upon waking* and the *day after* parameters (*feeling refreshed, motivated to get up, alertness, thinking, mood, sociability,* and *physical activity*). Of the pairwise interactions between these parameters, only *WASO* and *feeling refreshed* had a significant interaction ($p < 0.001$). This interaction judged a night with both *WASO* and *feeling unrefreshed* to be a particularly poor night's sleep. However, if participants either felt at least *somewhat refreshed* or if they *slept through* the night, then they judged it to be a reasonably good night's sleep.

Interactions between parameters of sleep quality judgement and types of sleeper

There was no significant interaction between parameters and types of sleeper, suggesting that whether the participant was a good or poor sleeper did not have a significant effect on their choices.

Interactions between parameters of sleep quality judgement and types of question

The interaction between parameters and types of question allowed us to statistically test whether participants used the same parameters to define a good and a bad night's sleep. Only one significant interaction was found between *feeling refreshed* and types of question (p= 0.003), suggesting that *feeling refreshed* was more important to the participants when judging a good night's sleep than when judging a poor night's sleep.

4.4 Discussion

Instead of asking people to give an abstract rating of their sleep quality, we asked people to make choices between two concrete scenarios and indicate with their choice which scenario represents a better (or worse) night's sleep. By conceptualising the sleep quality judgement as a decision-making process, we managed to quantitatively identify and estimate the relative importance of different sleep and non-sleep parameters in influencing their judgement of sleep quality. In this study, 11 out of 17 identified sleep quality parameters were found to have a significant effect on the participants' sleep quality judgement. In particular, the participants relied most heavily on *TST*, *feeling refreshed* (upon waking) and *mood* (day after) to make their judgement of sleep quality. The data also suggested that the participants' judgement of sleep quality was most influenced by their memories of what happened *during sleep* and their experience *upon waking,* followed by their feelings and functioning during the *day after*, then *pre-sleep* experience of the night before, and lastly their experience the *day* *before*. Synergetic effects were found (i) between *WASO* and *feeling refreshed* (upon waking); (ii) between *feeling refreshed* (upon waking) and types of question. However, whether the participant was a good or poor sleeper did not appear to make a difference in the way in which the sleep quality judgement was made. Below we ponder several themes/questions emerged from the findings.

Sleep quality judgement is influenced by multiple parameters spanning across different times of the day

This may in part explain why the field has thus far been unable to pinpoint what the defining feature of sleep quality is (Krystal & Edinger, 2008). Sleep is a behavioural state of reduced activity and people typically remember little of what happened during the hours of sleep (Perlis et al., 1997; 2001). In contrast, the feelings they have upon waking and their evaluations of their own mood and daytime performance are relatively more accessible information. It is understandable why participants in the current study drew on both their memory of nighttime sleep and experience during the day to retrospectively judge their sleep quality. This combined use of day and night information for judging sleep quality resonates with previous work suggesting a significant role of daytime impairments in the genesis of insomnia complaint (Buysse et al., 2007; Carey et al., 2005; Edinger et al., 2003; Harvey, 2002; Kyle et al., 2010; Lundh & Broman, 2000). The retrospective and inferential nature of the decision-making process also raises two interesting possibilities for future investigation. First, people's judgement of sleep quality may vary depending on the time of the day the question is presented and the amount of relevant information accessible for retrieval when the judgement is called for. Second, the judgement of sleep quality can potentially be altered by systematically restructuring a person's daytime experience or by reversing biases in their evaluation of their mood and daytime functioning.

In terms of the content of the information used, *TST*, *feeling refreshed* (*upon waking*) and *mood* (*day after*) were the top three parameters influencing the judgement of sleep quality. Interestingly, combinations of these top parameters bear striking similarity with some of the statements featured in the Dysfunctional Beliefs and Attitude about Sleep (DBAS; Morin et al., 2007), e.g., "I need 8 hours of sleep to feel refreshed and function well during the day" and "By spending more time in bed, I usually get more sleep and feel better the next day". It is possible that endorsement of rigid, unhelpful sleep beliefs can have a direct or indirect effect on people's judgement of sleep quality (Lundh & Broman, 2000; Harvey, 2002). This effect may not be restricted to people with insomnia disorders but also apply to those suffering from other sleep disorders such as sleep apnea, restless legs syndrome, hypersomnia or narcolepsy (Crönlein et al., 2014). We note though that in the "best preferred scenario" generated from the data of our participants, they indicated that they preferred 9.5 hours to 7.5 hours (which is closer to the typically expectation of 8 hours). This deviation may reflect the developmental sleep need of our participants whose mean age was 22.5 years at the time of the study (Groeger, Zijlstra, & Dijk, 2004; Hirshkowitz et al., 2015).

Pre-sleep cognitive arousal is not a significant parameter of sleep quality?

Of all pre-sleep parameters tested, only physiological arousal had a significant impact on the participants' judgement of sleep quality. This is in contrast to the established understanding that poor sleepers refer to cognitive arousal rather than physiological arousal as the premise of their insomnia (Lichstein & Rosenthal, 1980; Morin, Stone, Trinkle, Mercer, & Remsberg, 1993) and that hyperarousal during the pre-sleep period - manifested either cognitively as worry/rumination or physiologically as high-frequency beta EEG - is a strong predictor of subsequent low sleep quality (see Riemann et al. (2010) for a review). The null finding of pre-sleep cognitive arousal may be explained by how it was operationalised in our current study. In the sleep scenarios, the options given to the participants were: my mind was 'racing with thoughts', 'wandering with thoughts', or 'blank'. In retrospect, these choices only described the frequency of cognitive activity but not the tone of the cognitive activity. Potentially, a heightened amount of cognitive activity *per se* is not sufficient to alter people's sleep quality judgement. It may be essential that the heightened amount of cognitive activity is negative or even threat-provoking in order to sway people's perception of sleep quality (Harvey, 2002; Fichten et al., 1995).

WASO and feeling refreshed are not functionally synonymous, but interacting parameters of sleep quality?

The interaction suggests that if the participants did not sleep through the night and did not feel refreshed in the morning, they would be disproportionately more likely to come to the conclusion that they had had a poor night's sleep. However, if the participants somehow feel refreshed on waking, whether or not they have slept through the night would not be as important as it would normally be in their judgement of sleep quality. This finding raises the possibility that sleeping through the night may not a pre-requisite to feeling refreshed the next morning. The non-linearity is possible because, like sleep quality, feeling refreshed is a non-specific subjective judgement which may or may not be influenced by the sleep experience, post-sleep inertia and sensory input, and/or the person's ability to look forward to activities/excitement lined up for the day. Exploring ways to help people feel "refreshed" in the morning could potentially provide a new route to improve sleep quality among people with mild-moderate sleep maintenance problems, and we would like to propose two plausible avenues: (1) introducing attentional training that helps people with insomnia to reverse or diffuse attentional biases towards negative, threat-provoking sleep cues (Espie et al., 2006; Jones, Macphee, Broomfield, Jones, & Espie, 2005) and to apply heavier weights on positive memories and experience to inform their sleep quality judgement; (2) instead of focusing exclusively on nighttime experience, insomnia treatment may diversify to help patients regulate their physical and social activity during the day. Based on the findings of the current study, improved mood and perceived daytime functioning can influence a person's overall sleep quality judgement.

No systematic difference in the way good and poor sleepers judge their sleep quality

Although counterintuitive, this finding is consistent with the key observation from Harvey et al. (2008) in which normal sleepers and people with insomnia used broadly similar characteristics to describe a good/poor night's sleep when asked to define sleep quality or to explicitly state what is important for their judgement of sleep quality. Together, the findings from both Harvey et al. (2008) and our study appear to suggest that there are certain universal requirements for good-quality sleep shared between good and poor sleepers, and people with insomnia are not exaggerating their sleep quality requirements simply because of their distress or personal experience of sleeplessness. An intriguing question left unanswered is what sets these requirements? Are the requirements biological or socially determined through acculturation? Future anthropological studies comparing sleep quality parameters used by distinctive cultural groups with different sleep patterns and contexts may help address the question (Yetish et al., 2015).

Strengths and limitations

Several potential limitations of the current study should be discussed. First, the participants were young, generally healthy adults drawn from a university community. Such demographic background is restricted in diversity. Although the participants who had an ISI (Bastien et al., 2001) score of 8 or above and presented with insomnia symptoms that mapped onto the DSM-5 diagnostic criteria (American Psychiatric Association, 2013) were allocated to the poor sleeper group, they may not represent patients diagnosed with insomnia who are actively seeking medical or non-pharmacological treatment. Generalisability of the findings to the wider clinical population with more severe insomnia symptoms is yet to be determined. In relation to this, given the encouraging results generated by this study, future study should also consider exploring the judgement of sleep quality in more heterogeneous sample with varied characteristics (e.g., older population, people from different socio-economic spectra of the society, patients living with chronic medical/ psychiatric conditions etc.). Second, to maximise efficiency and statistical power of the study, administration of the choice-making task took place at different times of the day. Whilst we have tight control over the testing environment and the participants' use of stimulants, exposure to light, amount of activity and task-related fatigue during the testing period, we do not know to what extent the result could have been subject to the influence of circadian rhythm. To address this question, future follow-up studies may want to add measures of the participants' alertness levels at the start of the task and time the testing session according to the participants' circadian preference (e.g., morningness-eveningness; Horne & Ostberg, 1976). Third, to simulate the real-life decision-making process and to standardise the number of parameters used for making a sleep quality judgement, we asked the participants to read and imagine themselves being the person experiencing the sleep/wake scenarios, and then choose the one that best represents a better (or worse) night's sleep. Whilst detailed instructions were given to the participants, the extent to which they successfully identified themselves with the scenarios was not certain, although we did eliminate from the analysis data of those participants who responded too quickly to have engaged with the task. Also, whilst we gained ecological validity by simulating the decision-making process through combining different parameters of sleep quality, the choice-making task was nonetheless presented on a computer screen in an artificial testing environment. Future studies should consider situating the choice-making task within real-life scenarios as hypothetical situations can cause participants to overestimate or underestimate the effect parameters have compared to actual experience (Dolan & Kahneman, 2008) although sleep is arguably a near universal experience. It is fair to assume all participants have some degree of lived experience to support their imagination of good- and bad-quality sleep scenarios, which is not of the same degree of difficulty as though they were asked to imagine what quality of life they would have had they suffered from paraplegia (Brickman, Coates, & Janoff-Bulman, 1978) or had lost a limb to cancer (Tyc, 1992). That said, the current study was the first to examine the parameters of sleep quality using a quantitative choice-making approach. Using this method, we managed to string together different parameters from different time periods and examined the effect of time, sleepers, and interaction between parameters in explaining participant's sleep quality judgement. The sleep quality parameters were anchored to different concrete options (e.g., WASO: "I slept through the night.", "I woke up once or twice but only briefly.", "I woke up a number of times but only briefly.", "I woke up in the middle of the night and was eventually able to fall back to sleep.", "I woke up in the middle of the night and was unable to fall back to sleep"). This provided specific directions and a definition for each parameter in order to reduce differences in how participants interpreted parameters based on their previous individual sleep experiences. This is a methodological improvement over qualitative studies, interviews, questionnaires, and sleep diaries in extracting information relevant to sleep quality judgement. Readers with a statistical background may have noticed that there is a degree of correspondence between Item Response Theory (IRT) and choice-based conjoint analysis used in the current study. However, there is one important difference: the former is concerned with scale development, identifying the areas of greatest individual variability between individuals with a goal to distinguish those who have sleep disturbance or sleep-related impairment from those who do not, whereas, the latter is concerned with intra-individual differences in judgement across scenarios, with a goal to clarify what it means when a person says, 'I had a good/ bad night's sleep'. The application of IRT in the study of insomnia has been focused on scale development, which is diagnostic and predictive (Buysse et al., 2010; Yu et al., 2011). In contrast, the application of choice-based conjoint analysis in this study is more revelatory and retrospective.

Potential clinical implications

As the current study was the first attempt applying choice-based conjoint analysis to unpack the subjective meaning of sleep quality, we wish to be cautious in our extrapolation of what the findings might mean for clinical practice. However, if we were to speculate, the methodology described here has the potential to help us identify the specific factors that drive patient complaints of 'poor sleep quality', particularly in cases where 'objective' assessments of sleep showed no conclusive finding of sleep disturbance. This could help clinicians to understand potential causes of 'poor sleep quality' complaints of individual patients and accordingly narrow down areas that warrant treatment that may differ between patients.

Recent advances in digital technology have opened up numerous possibilities for eliciting information from patients. With a few tweaks in scenario sampling algorithms and data analysis approaches, the sleep quality judgement decision-making task like the one used in the current study could be run on smartphones, in combination with the recommended 2-week sleep diary assessment (Schutte-Rodin, Broch, Buysse, Dorsey, & Sateia, 2008). Aided by corresponding computer applications, clinicians can be provided with diagnostics based on these sleep quality judgement data for personalising the assessment and treatment plan, allowing the field to move yet another step closer towards patient-centred care (National Health Service, 2005; Kitson, Marshall, Bassett, & Zeitz, 2013; US Department of Health and Human Services, 2008; WHO, 2000) and personalised medicine (Smith, Barkin, & Barkin, 2011). Obviously, the automation of the diagnostic application would require research that shortens the elicitation procedure, perhaps by collecting a large number of trials from a variety of participants, so that new patients can be matched to this normative data using a small number of trials. Also, further research is needed to better understand whether factors such as circadian rhythm, day-to-day variability in sleep, use of sleep medication, social conventions (e.g., weekday/weekend distinction), and even weather (e.g., availability of sunshine) influence the sleep quality decision-making process, and if so, how.

Conclusion

In conclusion, sleep quality judgements appear to be determined by not only what happened during sleep, but also what happens after the sleep period. Interventions that improve mood and functioning during the day may inadvertently also improve people's subjective evaluation of sleep quality. The next chapter of the thesis shifts the focus to the association between sleep and physical activity.

Chapter 5

Study 3 - A Daily Process Study On The Association Between Sleep And Physical Activity In Healthy Young Adults

5.1 Introduction

Findings that emerged from the qualitative study in Chapter 3 and experimental study in Chapter 4 demonstrated that sleep quality judgement is not solely determined by nighttime parameters but also by people's feelings on waking, their cognitive functioning during the day, and their ability to engage in daytime physical and social activities. Importantly, findings from the qualitative study in Chapter 3 suggest that patients with chronic pain perceive sleep quality and pain experience as linked, and both of these factors can in turn, jointly or separately influence subsequent engagement in daytime physical activities.

Engagement in daytime physical activity has long been considered an important factor in maintaining good health. The World Health Organization (WHO) has identified physical inactivity as the fourth primary risk factor for global mortality (WHO, 2010) and recommended that adults should engage in at least 150 minutes of moderate-intensity aerobic physical activity (i.e., activity that involves a movement of large muscles in a constant period of time, such as walking, running, cycling) per week. A number of studies have systematically shown the long- and short- term benefits of performing physical activity, which includes a much reduced risk of cardiovascular disease, obesity, diabetes, and mental health problems (e.g., Bauman, 2004; Bauman et al., 2016; Benloucif et al., 2004; Lee et al., 2012). However, despite these desirable outcomes, engaging in physical activity can be difficult for some people and may not be so straightforward in people with existing health conditions. In England, approximately only 25% of women and 37% of men meet these recommended levels of physical activity (Allender, Foster, Scarborough, & Rayner, 2007).

Low physical activity level is a common consequence of chronic pain (Kop et al., 2005; van den Berg-Emons et al., 2007). In a prospective study of 2188 participants categorised into "no pain", "some pain" (pain reports which did not meet the American College of Rheumatology criteria for chronic widespread pain) or "chronic widespread pain" group, it was found that individuals with chronic widespread pain had increased odds of reporting "less-much less" physical activity 32 months later (RRR = 4.5: 95% CI 3.2-6.2) compared to participants who were free of chronic pain at baseline (McBeth et al., 2010). This result highlights that low levels of physical activity can be a consequence of chronic widespread pain.

Increasing the levels of physical activity in people with chronic pain is challenging given the constant presence of pain. Yet, it is important to promote and implement effective interventions to increase their physical activity levels because physical activity improves overall physical and mental health as well as reduces problems related to pain (e.g., disuse and physical deconditioning). Understanding the potential factors facilitating or hindering performance of physical activity will inform the design of appropriate interventions specifically for individuals with chronic pain.

Self-efficacy refers to an individual's belief about his/her capabilities in performing a particular behaviour or specific activity (Bandura, 1977; Turner, Ersek, &

Kemp, 2005) and has been identified as a psychological factor affecting physical activity and functioning among people with chronic pain (Buckelew, Murray, Hewett, Johnson, & Huyser, 1995; Denison, Åsenlöf, & Lindberg, 2004; Jackson, Wang, Wang, & Fan, 2014; Rejeski, Craven, Ettinger, McFarlane, & Shumaker, 1996; Turner et al., 2005). In particular positive associations have been found between high self-efficacy with the performance and persistence of exercise and stretching, although it is unclear whether self-efficacy is predictive of daily physical activity level. Possibly, the presence of positive association is due to a sense of control. A sense of control is important to the psychological and physical health and self-efficacy is regarded as a situation-specific form of control (McAuley & Blissmer, 2000).

Mood is another psychological factor associated with physical activity in chronic pain. Roshanaei-Moghaddam, Katon, and Russo (2009) conducted a systematic review to examine the effect of depression on physical activity. Of eleven longitudinal studies, eight studies demonstrated that depression at baseline negatively predicted reduced physical activity at follow-up. This finding is however not pain-specific, as those eight studies were based on data drawn from samples of the general population, older adults, patients with cardiovascular disease and diabetes. A couple of recent studies have filled this gap. Alschuler, Theisen-Goodvich, Haig, and Geisser (2008) reported that depression significantly predicted disability and physical performance in 267 patients with chronic pain even when controlling for age, gender, pain sites and intensity. Specifically higher levels of depression significantly predicted lower levels of physical performance ($p< .01$). However, the causal inferences of the relationship cannot be made because of the nature of cross-sectional data. Importantly, this finding is not replicated when the relationship is analysed from the within-person perspective. Using a daily process study, Tang and Sanborn (2014) analysed data from 119 heterogeneous patients with chronic pain and comorbid insomnia (mean age= 46 years) to assess the temporal relationship between morning mood and daytime physical activity. Participants were asked to rate their mood on a numerical rating scale every morning, for a week (i.e., *How would you describe your mood right now?;* from 0= very bad mood, to 10= very good mood). Multilevel models revealed that morning mood did not predict subsequent physical activity in heterogeneous patients with chronic pain comorbid insomnia (p= 0.79). The finding is in agreement with Vendrig and Lousberg's (1997) finding which showed no significant within-person relationship between mood and activity level in 57 patients with chronic pain (mean age= 42.3 years). Possibly, the non-significant findings of mood at the within-person association are due to the shorter time scale of mood and physical activity.

In addition to self-efficacy and mood, the role of pain should be taken into account. It has been suggested that chronic pain patients use pain severity or intensity as an indicator of how much they do or have the ability to engage in daytime physical activity (Mansfield, Thacker, Spahr, & Smith, 2017; Ramlee et al., 2016). The more severe the pain they experience, the less likely they were to engage in physical activity (Mansfield et al., 2017; Stubb, Hurley, & Smith, 2015). If this persists in the long run, it can become a cycle of disability and pain (Lin et al., 2011; Vlaeyen & Linton, 2000); people with chronic pain became physically less active and more sedentary with more pain severity. Eventually prolonged rest could result in physical deconditioning and intolerance of physical activity (Bousema, Verbunt, Seelen, Vlaeyen, & Knottnerus, 2007; Verbunt et al., 2003; Verbunt, Smeets, & Wittink, 2010). However, the association between pain severity/ intensity and physical activity is somewhat weak or still lacking. Using the Experience Sampling Method (ESM), Vendrig and Lousberg (1997) investigated the within-person relationships between pain intensity and activity level in 57 patients with chronic pain (mean age= 42.3 years). The ESM is a structured diary technique that assesses participant's subjective experiences by asking them to repeatedly complete the diary at a random time schedule. The participants were asked to rate their pain intensity and activity level eight times a day (i.e., between 8.30am to 10.30pm) for six days. A wristwatch (Seiko RC-100) alarm was used to send signals at the time when the participants had to rate their pain intensity and activity level. Pain intensity was assessed using seven-point likert scale from 0 (no pain) to 6 (very much pain) and activity level was also assessed using seven-point likert scale from 0 (rest, lying, doing nothing) to 6 (heavy physical work). Pearson r was used to examine the within-person correlation of pain intensity and activity level. Mean correlation between pain intensity and activity was not significant ($p > .05$). The findings did not support the association between pain intensity and activity level.

Related to pain, fear of pain or (re)injury has been identified as a crucial factor determining one's engagement in daily physical activity. According to the fear-avoidance model (Vlaeyen & Linton, 2000), greater fear of pain has led people with chronic pain to use maladaptive coping strategies such as activity avoidance (Al-Obaidi, Nelson, Al-

Awadhi, & Al-Shuwaie, 2000; Basler, Luckmann, Wolf, & Quint, 2008; Edwards, Bingham, Bathon, & Haythornthwaite, 2006; Hasenbring & Verbunt, 2010; Huijnen et al., 2010; Turk, Robinson, & Burwinkle, 2004; Verbunt et al., 2005). Turk et al. (2004) examined fear of pain in 233 patients with fibromyalgia (mean age= 43.79 years). Fear of pain was assessed using a self- report instrument (i.e., Tampa Scale Kinesiophobia). The Tampa Scale Kinesiophobia comprised 17 items that asked participants to rate their responses on a 4-point likert scale. Higher scores indicate greater fear of pain. Findings revealed that participants with high levels of fear of pain demonstrated greater disability (t= 4.02, p< .001), pain severity (t= -2.71, p< .01) and lower treadmill performance (t= -2.39, p< .05) compared to participants with low fear of pain.

Hasenbring et al. (2012) found that patients with chronic pain who engaged in activity avoidance (e.g., patients who stop doing physically demanding activities, avoid visiting friends) demonstrated a higher level of pain catastrophising compared to those who engaged in adaptive responses (i.e., flexible responses to pain such as breaking up activity into manageable pieces). As such the patients believe that performing physical activity would increase their pain intensity. Hence patients with activity avoidance showed signs of underuse in their daily behaviour (Hasenbring, Plaas, Fischbein, & Willburger, 2006). However, it has also been found that some people with chronic pain persist in performing physical activity in spite of severe pain (Hasenbring & Verbunt, 2010; Huijnen et al., 2011). Hasenbring et al. (2006) classified 24 patients with low back pain into “adaptive coping”, “endurance coping” and “fear avoidance coping”. Their physical activity level was assessed using an accelerometer worn by the patients for 8 hours a day. The “endurance coping” group showed similar physical activity level with “adaptive coping” group but had significantly higher pain scores and higher number of static strain postures (i.e., sitting, standing, forward sitting, forward standing). The patients with endurance coping demonstrated overactivity in spite of pain compared to patients with “adaptive coping”. Meanwhile, the “fear avoidance” patients appeared to do less physical activity and exhibit a low number of static strain postures.

Leonhardt et al. (2009) used a longitudinal design to investigate the association between fear-avoidance beliefs and physical activity level in 787 patients with acute (*n*= 449) and chronic (*n*= 338) low back pain. Patients were followed up over a period of one year. Fear-avoidance belief was measured using the Fear-Avoidance Beliefs Questionnaire (German version) and physical activity level was assessed using the Freiburger Questionnaire on Physical Activity. The structural equation results showed that fear-avoidance beliefs did not predict physical activity level. Using a cross-sectional design, Helmus, Schiphorst Preuper, Hof, Geertzen and Reneman (2012) examined the relationship between habitual coping strategies (i.e., active, passive, activity avoidance) and activity level in 53 patients with chronic musculoskeletal pain. Habitual coping was assessed using the Utrecht’s Coping List and activity level was assessed using the triaxial accelerometer. Participants were asked to wear the accelerometer for seven days. The findings revealed that there were no significant associations between different types of habitual coping and objectively assessed physical activity. Taken together, these studies show that there are variations in responses depending on the beliefs they hold.

Potentially there might be other primary factors that influence their engagement in physical activity.

Sleep is potential key determinant of physical activity in the regulation of day-to-day physical activity in people with chronic pain. Sleep is necessary for the body to restore energy and function normally (Harrison, 2012). The interaction between sleep and physical activity would maintain the sleep-wake cycle and circadian rhythm (van Someren & Riemersma-Van Der Lek, 2007). Van Someren and Riemersma-Van Der Lek (2007) highlight that it is important to keep a regular exposure to light and physical activity. It is because regularity would synchronise within and between the central circadian clock and peripheral oscillators. Sleep disturbance could interrupt the sleep-wake cycle and inactivity that weakens the homeostatic drive for sleep (Smith et al., 2009). In people with chronic pain, sleep disturbance has also been suggested to interrupt the central pain processing resulting in more pain, low mood and decreased physical functioning (Smith et al., 2009).

Previous studies have suggested that poor sleep quality is associated with slower walking speed, poorer performance to complete sit-to-stand tasks or narrow walk test and worse daytime functioning in older population, ≥65 years of age (Dam et al., 2008; Goldman et al., 2007). Schmid et al. (2009) examined the effect of sleep loss on physical activity in healthy normal-weight men. Using a counterbalanced crossover design, participants underwent 2 consecutive nights of 8 hours of sleep and then 2 consecutive nights of 4 hours of sleep. Results showed that short-term sleep loss significantly reduced overall spontaneous daytime physical activity. In addition, findings from a survey conducted in 10 European countries showed that people who slept less than 8 hour per day were more sedentary and had higher BMI (Garaulet et al., 2011). Similarly, Booth et al. (2012) found that participants with parental history of type 2 diabetes who slept less than 6 hours per night were less physically active and more sedentary than their counterpart who slept more than six 6 hours per night. Collectively, these studies highlight the role of sleep in influencing physical activity.

While most of the previous studies have investigated the between-person relationships, there are a handful of studies that examine the within-person relationships between sleep and physical activity on a day-to-day basis. These studies were primarily limited to specific populations at risk of sleep disturbance and physical inactivity, such as patients with cancer (Bernard, Ivers, Savard, & Savard, 2016), women with insomnia (Baron et al., 2013), working mothers (Fortier, Guerin, Williams, & Strachan, 2015), older women (Lambiase, Gabriel, Kuller, & Matthews, 2013) and, individuals with and without bipolar disorder (McGlinchey, Gershon, Eidelman, Kaplan, & Harvey, 2014).

An interesting finding from a recent daily process study suggests that in the absence of intervention, better sleep quality is associated with a spontaneous increase in physical activity in patients with chronic pain (Tang & Sanborn, 2014). Put simply, for the same individual, nights of better sleep quality are followed by days of more physical activity, compared with nights of poorer sleep quality that is followed by days of lower physical activity. In contrast, neither pain nor mood in the morning was a significant predictor of subsequent physical activity during the day. This study is interesting as it is the first to show a temporal association of sleep quality with subsequent daytime physical activity in chronic pain. Whilst these findings were promising, it remains unclear to what extent these results could be applied to the population of different demographic and/or clinical characteristics (e.g., pain-free individuals without symptoms of insomnia). Tang and Sanborn's study physical activity was derived from actigraphic data. Whilst these data provided a quantitative index of the level of physical activity, they did not give qualitative information on the types and nature of the recorded physical activity.

Having discussed how sleep could influence physical activity, the following paragraph will address how physical activity could also influence sleep. For instance, results from the meta-analysis of 12 studies comprising 3144 participants indicated that adolescents and young adults (aged 14 to 24 years, mean age= 17.8 years) with higher physical activity measured both by subjective and objective assessment were more likely to experience better sleep quality (Lang et al., 2016). The studies included in the meta-analysis consisted of mostly cross-sectional studies and one longitudinal study with randomized-controlled trial design (i.e., data from the baseline was excluded from the analysis). Physical activity was measured using pedometers, accelerometers and questionnaires. Meanwhile sleep quality was assessed using questionnaires (e.g., PSQI, ISI), sleep diary and sleep-EEG in participants' homes. Besides, Lang et al. (2013) reported that subjective assessment of physical activity level was a better predictor of a good night's sleep compared to objective assessment of physical activity. Moreover, in a randomized controlled trial, older adults with insomnia (mean age= 61.6 years) who performed moderate intensity aerobic physical activity (i.e., walking, stationary bicycle or treadmill four times per week, for 16 weeks with 20-40 minutes per session) and received sleep hygiene education showed improvement at follow-up pre-post comparisons in sleep quality, sleep latency and sleep efficiency compared to those who only received sleep education hygiene (Reid et al., 2010). Reid et al. (2010) also found that older adults with insomnia in the aerobic physical activity group exhibited significant improvement in the PSQI scores at follow up 16 weeks later ($t(15)= 5.62$, $p<$ .0001). Meanwhile older adults in the control group did not show any significant improvement in their PSQI scores. Engagement in minimal level of physical activity per week (150 minutes of moderate-intensity activity) significantly reduced insomnia symptom severity among inactive adults with insomnia (Hartescu, Morgan, & Stevinson, 2015), whereas maintaining and/or increasing a medium or high level of leisure physical activity over 10 years reduced women from the risk of insomnia (Sporndly-Nees, Asenlof, & Linberg, 2017). Hartescu et al. (2015) chose 150 minutes of moderate-intensity activity as it is the recommendation from public health guidelines for a minimum level of physical activity per week. However, these findings contradict daily process study evidence that demonstrated no significant within-subjects associations between physical activity and sleep among normal sleepers (Youngstedt et al., 2003).

Overall, there seems to be some evidence to indicate that the relationship between sleep and physical activity is bidirectional. However findings on the effect of sleep on physical activity appear to be more consistent than those supporting the effect of physical activity on sleep. Therefore, the present study aimed to examine the association between sleep and next day physical activity, and the association between daytime physical activity and subsequent sleep on a day-to-day basis. Using the daily process approach, this study explored the temporal nature of the within-person relationship in healthy young adults. This study was conducted with healthy young adults to rule out the influence of comorbid psychiatric and medical symptoms and the use of medications. The present study adapted the work established in Tang and Sanborn's (2014) study and hypothesised that healthy individuals who have a better night's sleep would be more likely to engage in higher level of daytime physical activity the next day and those who have a higher level of daytime physical activity would be more likely to have a better night's sleep on the subsequent night. In addition, the present study explored the association between sleep and different types of physical activity (i.e., running, walking, standing, sitting, lying down).

5.2 Methods

5.2.1 Design

A daily process study was conducted with 124 healthy young adults to examine the temporal relationship between sleep and physical activity. Figure 5.1 illustrates the design of the study, which required the participants to keep a sleep and physical activity diary about their sleep and physical activity for 7 days, in their natural living and sleeping environment. The sleep diary asked participants to record their bedtime, get up time, sleep onset latency, number and duration of awakenings during the night and sleep quality rating. The physical activity diary asked participants to record the subjective rating of their overall level of physical activity and time spent on different types of activity. The participants completed the sleep diary in the morning on waking based on the sleep they had on the previous night, and the physical activity diary at bedtime based on the activity they had during the day. The data collected were therefore time-specific and can be used to explore the temporal effect of sleep on next day physical activity (see dotted arrows in Figure 5.1) and the effect of physical activity on the subsequent sleep (see solid arrows in Figure 5.1). In other words, instead of examining the association between sleep and physical activity between-person, the current study focused on the within-person temporal relationship between sleep and physical activity. The study protocol had received full ethical approval from Department of Psychology Research Ethics Committee.

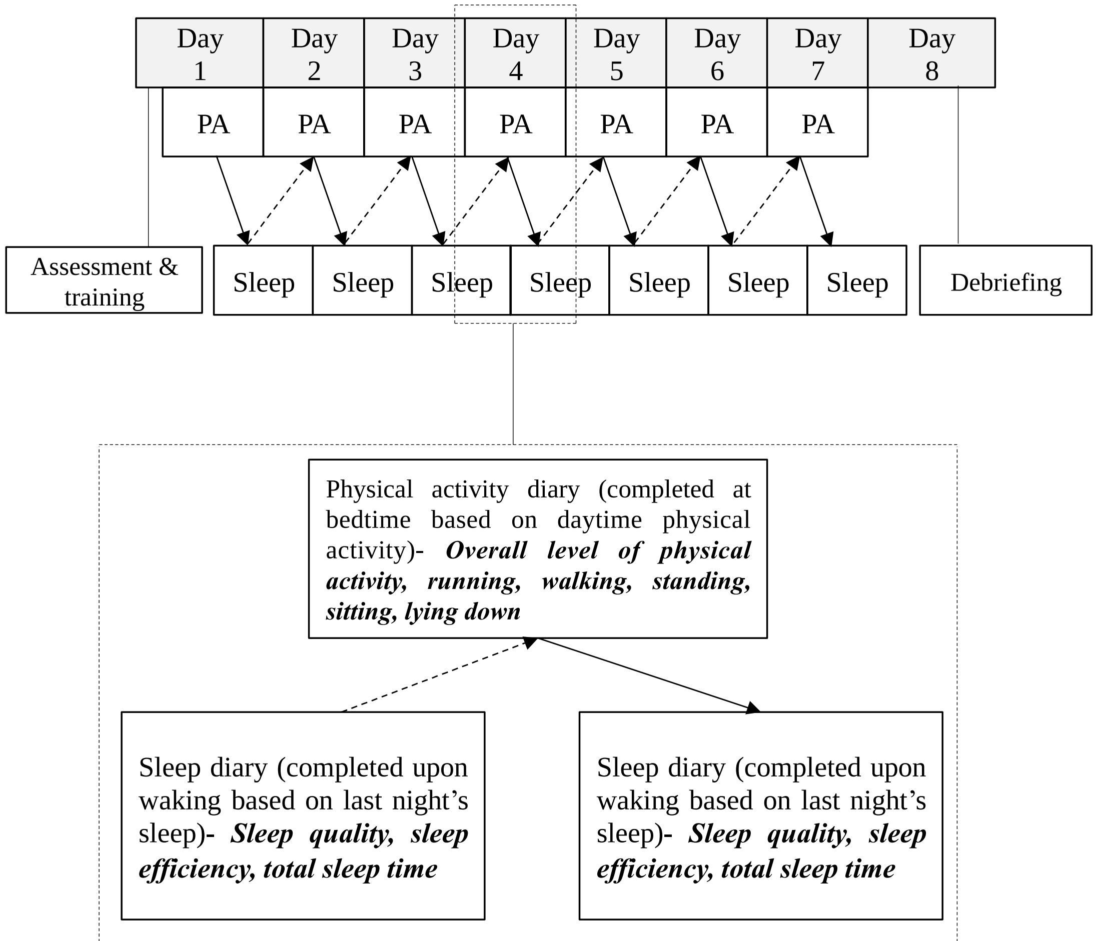

Figure 5.1 Study design and variables assessed by sleep diary (i.e., sleep quality, sleep efficiency, total sleep time) and physical activity diary (i.e., overall level of physical activity, running, walking standing, sitting, lying down).
PA= Physical activity. Dotted arrow= Sleep predicted physical activity.
Solid arrow= Physical activity predicted sleep.

5.2.2 Sample size

Sample size estimation for the multilevel models was not performed using conventional methods (Field, Miles & Field, 2012). Instead, the sample size was estimated based on the previous studies with similar design (e.g., Affleck et al., 1996; Russell, Wearden, Fairclough, Emsley, & Kyle, 2016; Tang, Goodchild, Sanborn, et al., 2012; Tang & Sanborn, 2014; Vendrig & Lousberg, 1997). Of the previous studies with similar daily process design, approximately 27 to 119 participants generate observation ranging from 162 to 1500. The data attrition rates in these studies were around 10% to 30% and the attrition was mainly due to incomplete data. Thus, a sample size of 118 in the present study will give 826 observations and sufficient power to absorb likely data attrition and for modeling the within-person relationship between sleep and physical activity and vice versa.

5.2.3 Participants

Participants of the current study comprised healthy young adults recruited from a university-wide subject panel. Potential participants were included in the study if they (1) were aged between 18 and 65 years, (2) were English speaking, (3) were generally healthy with no known major psychiatric illness (e.g., psychosis), neurological conditions (e.g., dementia) or life threatening medical condition (e.g., cancer, HIV) that would prevent the provision of informed consent and full participation in the study. Potential participants excluded from the study were those who (1) had pain of <6 months as a result of illness, surgery or injury, (2) had any malignant or non-malignant chronic pain for at least 6 months (e.g., arthritis, back pain, fibromyalgia etc.), (3) had any other known sleep disorders that might explain sleep disturbance (e.g., sleep apnoea, restless leg syndrome/periodic leg movement syndrome, narcolepsy). However, those who reported to have insomnia were not excluded. Of 124 participants, 4 participants were excluded due to the presence of non-malignant chronic pain. A further two participants were excluded due to incomplete sleep diary, which resulted in >30% of missing data from sleep diary. Hence the final sample for data analysis comprised 118 participants.

5.2.4 Procedure

A participant recruitment advertisement with the detailed information of the study was displayed on the University Research Participation Website (https://warwick.sona-systems.com/Default.aspx?ReturnUrl=/). Individuals who responded to the advert were invited to attend an assessment interview at the Warwick Sleep and Pain Laboratory. During the assessment interview (on Day 1), potential participants were screened based on the inclusion and exclusion criteria (see section 6.2.3). Following the screening, written informed consent was taken from the included participants, who were asked to complete a set of questionnaires that took approximately 10 minutes to finish. The questionnaires contained items measuring the participant's demographics, chronotype and typical sleep patterns (see section 6.2.5, the *Questionnaires* sub-section for details). Once the participants had completed the questionnaire, they were provided with one-to-one training on how to answer each item on the paper-and-pencil sleep diary and physical activity diary. In addition, the participants were given written guidelines that explained each item of the diaries, so, if necessary, they could refresh their memory of the monitoring procedure at home. The purpose of the training was to ensure that the participants would be able to complete the monitoring task efficiently and the diaries correctly. The participants were sent home to start the data collection once they had demonstrated understanding of the task by successfully completing one set of training diary.

The data collection process was 7 days long and all participants completed 7 days worth of diaries. During this period, the participants were advised not to change their usual sleep-wake pattern, typical daily activity routine, use of medication (e.g., contraceptive pill), and consumption of coffee/ tea, alcohol and/or tobacco during the study. This was to minimise unwanted or unmeasured confounders that might influence the findings. They were asked to complete the physical activity diary every night at bedtime and the sleep diary every morning on waking. Specifically they were asked to complete the diaries within 30 minutes of their bedtime and 30 minutes within their get up time. To minimise potential sleep-interfering effect of the monitoring procedure, the participants were advised to avoid the clock monitoring and just provided the best estimate they could when completing the diaries.

After seven days of data collection (on Day 8, see Figure 5.1), the participants came back to the laboratory to return the sleep and physical activity diaries. The participants were debriefed on their participation (i.e., given the opportunity to express concerns about the study, and asked if they had any problems as a result of taking part in the study). They were also reimbursed £7 or were given course credit for their participation.

5.2.5 Measures

Sleep diary

Sleep was assessed using the Consensus Sleep Diary (CSD, (Carney et al., 2012; see Appendix 12). The sleep diary contained 9 items asking the participants to record their bedtime ("What time did you get into bed?"; "What time did you try to go to sleep?") and rise time ("What time was your final awakening?"; "What time did you get out of bed for the day?"). It also asked the participants to estimate their sleep onset latency (SOL, "How long did it take you to fall asleep?"), how many times and for how long did they wake up after sleep onset (WASO, "How many times did you wake up, not counting your final awakening?"; "In total, how long did these awakenings last?"), and to rate the quality of their sleep (SQ, "How would you rate the quality of your sleep?") on a numerical rating scale from 0 (very poor) to 10 (very good). Information gathered by the participants using the sleep diary was used to calculate sleep efficiency (SE), total sleep time (TST) and time in bed (TIB). SE was calculated based on the formula: TST/TIB * 100. Whilst TST was estimated based on the formula suggested by Morin and Espie (2003): TIB-(SOL+WASO duration). SQ, SE and TST were chosen as the key sleep variables derived from the sleep dairy data to be included as predictors and outcomes in the multilevel modeling. These variables were chosen to maximise comparability of the present findings with the past studies. Moreover, SE was an important index of sleep continuity or sleep consolidation.

Physical activity diary

Physical activity was assessed using the physical activity diary (see Appendix 13). The physical activity diary contained 6 items asking the participants to rate their overall level of physical activity (“How physically active have you been today?”) on an 11-point numeric rating scale from 0 (not at all active) to 10 (very active) and time spent doing different kinds of activities, which were running, walking, standing, sitting and lying down (“How much time did you spend doing the following activity during the day?”) on the response scale ranged from 0 (not at all) to 10 (a lot of the time). Apart from using the overall level of physical activity, times spent on different types of activity (i.e., running, walking, standing, sitting, lying down) were also included as predictors and outcomes in the multilevel modeling. These activities provided the types of individual’s daily activity and the duration they spent on those activities. The timeframe of physical activity spanned from the participants’ individual get up time to bedtime.

Questionnaires

The questionnaires included items to assess the participants’ demographics (age, sex, ethnicity, body mass index), the Morningness-Eveningness Questionnaire (MEQ; Horne & Ostberg, 1976) and the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) (see Appendix 11). The data collected from the questionnaires were used to describe and characterise the participants in the study.

Morningness-Eveningness Questionnaire (MEQ): The MEQ was used to assess chronotype or circadian rhythms. The MEQ contains 19 questions assessing participant differences in rise time and bedtimes, alertness and time an individual prefers to perform various activities. The score from each item was added together to sum up a total score. The total scores range from 16 to 86 and are categorised into five different chronotypes, which are “Definitely morning type (70-86)”, “Moderately morning type (59-69)”, “Intermediate (42-58)”, “Moderately evening type (31-41)”, and “Definitely evening type (16-30)”. The MEQ has demonstrated good internal consistency with Cronbach α = 0.86 and concurrent validity of correlations with oral temperature variables= 0.37- 0.79 (Horne & Ostberg, 1976).

Pittsburgh Sleep Quality Index (PSQI): The PSQI was used to assess sleep patterns and severity of sleep disturbances during the past month. It contains 19 items that are grouped into seven components namely subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medications and daytime dysfunction. Each component scores ranges from 0-3 and the seven component scores are summed up to yield a global PSQI score. The global scores range from 0 to 21, with higher scores indicating worse sleep quality. The PSQI has shown to have good internal consistency, Cronbach α = 0.83 and concurrent validity (e.g. correlation with polysomnography variables = 0.33- 0.47) in the sample of good sleepers/ healthy control, patients with depression and sleep disorders (Buysse et al., 1989). The psychometric properties of the PSQI have been examined in various clinical and non-clinical populations (Mollayeva et al., 2016). The total score of 5 or above on the PSQI has been suggested as the clinical cut-off for sleep disturbance.

5.2.6 Data Analysis

The statistical software R (https://www.rstudio.com/products/rstudio) was used to analyse data. There were two sources of data in the study, which were from the questionnaire and sleep and physical activity diaries. Data from the questionnaire were analysed using descriptive statistics, whereas data from the sleep and physical activity diaries were fit with multilevel models (Field, Miles & Field, 2012).

Descriptive statistics

Descriptive statistics on the questionnaire data were used to characterise the participants in the study. Frequencies and percentages were presented for categorical variables, while means and standard deviations were reported for continuous variable.

Multilevel models

The “lme4” package was utilised to fit multilevel models to the data. Two sets of analyses were run to examine the effect of sleep on physical activity the following day and to examine the effect of physical activity on subsequent sleep. For the first analysis, to examine the within-person temporal association between sleep (i.e., sleep quality, sleep efficiency, and total sleep time as the predictors) and physical activity the following day (i.e., overall level of physical activity, running, walking, standing, sitting, and lying down as the outcome variables), the daily monitoring data were pooled together from 118 participants, generating an aggregate data set of 708 observations across 6 days. The multilevel models built in the present study considered variations in the relationship between sleep and physical activity at both the "Day" level (Level 1) and the "Participant" level (Level 2). By adding these random effects into the models, the models would have different intercepts for different days as well as different intercepts for different participants. In the model equation [$Y_{ij} = \beta_{oj} + \beta_1 X_{ij} + E_{ij}$], Y represents the outcome (e.g., physical activity), i represents a particular case of data, j represents the level of the variable over which the intercepts varies (e.g., day), β_o represents the intercept, β_1 represents the slope of, X the predictor (e.g., sleep quality) and E represents random error.

The models were developed and analysed in a series of steps. First, the null model contains only random intercepts at both the "day" and "participant" levels (i.e., containing only a constant term- C only in Table 3 and 4). In the second model, a single predictor was added to the null model to examine its fixed effect (e.g., constant + sleep quality). Third, a likelihood ratio test (LRT, using the anova() function in r) was performed to compare the null model with the model with a predictor of interest. A significant difference between the two models, as indicated by a *p*-value below the critical level of significance ($p < .05$), suggested the alternative model being a better model than the null model. For example, a LRT assessed the significance of sleep quality by comparing the null model (e.g., constant, -log likelihood = -1496) with the alternative model (e.g., constant + sleep quality, -log likelihood = -1495). The *p*- value indicates whether the alternative model was significantly better than the null model (e.g. p= 0.109). The above three steps were repeated to build models with each possible predictors and outcomes. Altogether, 24 models were developed and analysed (i.e., 4 sleep predictors for each of the 6 physical activity outcome variable).

To overcome issues of multicollinearity and interaction between predictors, none of the models contains more than 1 predictor of interest. Relative strength of individual predictors were indicated by a between model comparison. Akiake Information Criterion (AIC) values were used to compare the strengths of the predictors to each other. The AIC is a goodness of fit index that is adjusted for model complexity, with smaller AIC values indicating a better model (Field, Miles & Field, 2012).

In the second analysis, to investigate the within-person temporal link between physical activity during the day (i.e., level of physical activity, running, walking, standing, sitting, and lying down as the predictors) and subsequent sleep (i.e., sleep quality, sleep efficiency, and total sleep time as the outcome variables), the daily monitoring data were pooled together from 118 participants, generating an aggregate data set of 826 observations across 7 days. The analysis took into account variations in the relationship between physical activity and sleep at both the "Day" level (Level 1) and the "Participant" level (Level 2). Thus, 21 models were created and analysed (i.e., 7 physical activity predictors for each of the 3 sleep outcome variable) by applying the same steps described for the first set analysis.

5.3. Results

5.3.1 Participant characteristics

Table 5.1 presents the demographics and sleep characteristics of the participants who had a mean age of 19.5 years (SD= 2.09) and BMI of 21.3 (SD= 3.84). They were predominantly female (79.7%) and white (61%).

Their mean score of 6.09 (SD= 2.95) on the PSQI was just above the clinical cut off (>5; Buysse et al., 1989) indicating 51.3% of the participants could be considered as “poor sleepers” and 48.7% as “good sleepers”.

According to the scores of MEQ, approximately half of the participants (45.8%) fell into the category of “Intermediate type”, 30.5% “moderately evening type”, 7.6% “definitely evening type”, 15.3% “moderately morning type”, and 0.8% “definitely morning type” in terms of their chronotype.

Table 5.1 *Participants' characteristics*

		n= 118	%
Demographics characteristics			
Age (18-30, in years)		19.5 (2.09)	
Body mass index		21.13 (3.84)	
Sex	Male	24	20.3
	Female	94	79.7
Ethnic origins	White	72	61
	White Irish	0	0
	Asian or Asian British: Chinese	24	20.3
	Asian or Asian British: Indian	7	5.9
	Asian or Asian British: Pakistani	6	5.1
	Asian or Asian British: Asian other	3	2.5
	Black or Black British	1	0.8
	British mixed	3	2.5
	Other	2	1.7
Sleep characteristics			
Morningness-Eveningness Questionnaire	Definitely evening type	9	7.6
	Moderately evening type	36	30.5
	Intermediate	54	45.8
	Moderately morning type	18	15.3
	Definitely morning type	1	0.8
Pittsburgh Sleep Quality Index	Total score, 0-21	6.09 (2.95)	
	"Good Sleepers" (<5)	57	48.7
	"Poor Sleepers" (5 or above)	60	51.3

Notes. Data were based on 118 participants except for BMI (*n*= 113) and PSQI total score (*n*= 117) as there were missing data. Data are presented as mean values with standard deviations in brackets, except for sex, ethnic origins, type of sleepers (PSQI) and chronotype (MEQ) where frequency are reported.

As can be seen from Table 5.2, sleep pattern from sleep diary data showed that participants, as a whole, achieved an average 93.7% (SD= 10.16) sleep efficiency, 7.45 (SD= 2.03) hours of sleep and, a rating of 6.67 (SD= 1.89) for sleep quality. Participants took an average of 21.64 (SD= 18.73) minutes to fall asleep and woke up once during the night (WASO) with a mean wake duration of 10 minutes (SD= 13.59). There were significant differences between good and poor sleepers on all sleep variables, except for the number of time awake after sleep onset where there was no difference between good and poor sleepers.

Table 5.2 *Participants' sleep patterns (derived from sleep diary data)*

Sleep pattern		Group total *n*= 118	Good sleepers *n*= 57	Poor sleepers *n*= 60	Comparison between good and poor sleepers
Sleep Diary	Average SQ (NRS 0-10)	6.67 (1.89)	7.13 (1.09)	6.20 (1.26)	t(115)= 4.25***
	Average SE (%)	93.17 (10.16)	95.33 (2.88)	91.22 (7.81)	t(75.51)= 3.81***
	Average TST (hour)	7.45 (2.03)	7.72 (0.85)	7.11 (1.41)	t(98.18)= 2.87***
	Average SOL (mins)	21.64 (18.73)	15.81 (10.15)	26.68 (22.88)	t(82.24)= -3.35***
	Average WASO (times)	1	1	2	t(115)= -1.72
	Average WASO duration (mins)	10 (13.59)	6.35 (7.88)	12.87 (16.9)	t(84.43)= -2.69***

Notes. Data are presented as mean values with standard deviations in brackets, except for WASO (times) where frequency are reported. SQ= Sleep quality. SE= Sleep efficiency. TST= Total sleep time. SOL= Sleep onset latency. WASO= Wake after sleep onset. mins= minutes. ***$p < .001$.
There was a missing data from PSQI total score and thus good sleeper group consisted of 57 participants and poor sleeper group consisted of 60 participants.

Table 5.3 *Participants' physical activity patterns*

Physical activity pattern		Group total *n*= 118	Good sleepers *n*= 57	Poor sleepers *n*= 60	Comparison between good and poor sleepers
Activity Diary	Average level of PA (NRS 0-10)	5.14 (1.31)	5.28 (1.39)	5 (1.23)	t(115)= 1.13
	Average running	1.42 (1.64)	1.63 (1.81)	1.21 (1.45)	t(115)= 1.4
	Average walking	4.99 (1.53)	5.08 (1.44)	4.9 (1.62)	t(115)= 0.59
	Average standing	3.99 (1.57)	4.02 (1.46)	3.95 (1.69)	t(115)= 0.22
	Average sitting	6.23 (1.46)	6.17 (1.38)	6.25 (1.56)	t(115)= -0.3
	Average lying down	3.7 (1.8)	3.34 (1.89)	4 (1.64)	t(115)= -2.01*

Notes. Data are presented as mean values with standard deviations in bracket. Level of PA= Level of physical activity. *$p < .05$.
There was a missing data from PSQI total score and thus good sleeper group consisted of 57 participants and poor sleeper group consisted of 60 participants.

5.3.2 Multilevel models for exploring the effects of previous night's sleep on next day physical activity

Multilevel models were fit to explore the effect of previous night's sleep (SQ, SE, TST) on next day physical activity (overall level of physical activity, running, walking, standing, sitting, lying down). Table 5.4 shows a summary of the results of these models, with outcome variables, predictors, fixed coefficient of the predictor(s), the negative log maximum likelihood values, the significance of the predictor(s), and the AIC values. Smaller AIC values suggested better models.

As shown in Table 5.4, SQ, SE, and TST were not significant predictors of the overall level of physical activity, the amount of time running, standing and sitting the next day. Among all sleep predictors, only TST predicted the duration spent walking (p = 0.044). The less the total sleep time of the previous night, the more time the participants spent walking the next day; the longer the total sleep time of the previous night, the less time the participants spent walking the next day.

SQ was found to be a significant predictor of the duration spent lying down (p = 0.0008). The better the sleep quality of the previous night, the less time people spent lying down on the subsequent day; the worse the sleep quality of the previous night, the more time people spent lying down. Neither SE nor TST was a significant predictor of the amount of time lying down.

Table 5.4 *Results of the multilevel models for exploring the effects of previous night's sleep on next day physical activity*

Outcome	Predictor	Fixed coefficient	LRT -Log likelihood	LRT *P*- value	AIC
Level of PA	C	5.132	1496	n.a	3001.0
	C + SQ	4.649, 0.072	1495	0.109	3000.4
	C + SE	5.373, -0.002	1496	0.751	3002.9
	C + TST	5.637, -0.001	1495	0.084	3000.0
Running	C	1.436	1465	n.a	2938.2
	C + SQ	1.035, 0.06	1464	0.168	2938.4
	C + SE	1.882, -0.004	1464	0.538	2939.9
	C + TST	1.305, 0.0002	1465	0.636	2940.0
Walking	C	4.896	1513	n.a	3035.7
	C + SQ	4.667, 0.034	1513	0.461	3037.2
	C + SE	4.922, -0.0002	1513	0.973	3037.7
	C + TST	5.5007, -0.001	1511	0.044*	3033.7
Standing	C	3.963	1500	n.a	3008.4
	C + SQ	3.746, 0.032	1499	0.482	3009.9
	C + SE	3.464, 0.005	1500	0.516	3009.9
	C + TST	4.427, -0.001	1498	0.116	3007.9
Sitting	C	6.124	1425	n.a	2859.3
	C + SQ	5.603, 0.078	1423	0.057	2857.7
	C + SE	5.75, 0.004	1425	0.586	2861.0
	C + TST	5.822, 0.0006	1425	0.250	2860.0
Lying down	C	3.726	1508	n.a	3024.4
	C + SQ	4.755, -0.154	1502	0.0008***	3015.3
	C + SE	3.618, 0.001	1508	0.888	3026.4
	C + TST	3.50, 0.0005	1507	0.441	3025.8

Notes: LRT= Likelihood ratio test. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$. - Log likelihood= the negative log maximum likelihood. C= Constant. Level of PA= Level of physical activity. SQ= sleep quality. SE= Sleep efficiency. TST= Total sleep time. n.a= Not applicable.

5.3.3 Multilevel models for exploring the effects of daytime physical activity on subsequent sleep

Multilevel models were fit to explore the effect of physical activity (overall level of physical activity, running, walking, standing, sitting, lying down) on subsequent sleep (SQ, SE, TST). Table 5.5 presents a summary of the results for these models.

As presented in Table 5.5, the overall level of physical activity and the amount of time spent running, walking, standing, sitting and lying down were not significant predictors of subsequent SQ and SE. Among all predictors, the overall level of physical activity (p = 0.028), the amount of time spent running (p = 0.021) and lying down (p = 0.0008) were independently found to be significant predictors of TST. Those who reported lower levels of physical activity, less time running and more time lying down during the day were also those who reported longer total sleep time during the night; those who reported higher levels of physical activity, more time running and more time lying down during the day were also those who reported shorter total sleep time during the night. Intuitively, this suggests a simple reciprocity of opportunity such that the less time people being active during the day (e.g., lower overall level of physical activity, more lying down), the longer they sleep during the night. Figure 5.2 presents results summary of the multilevel models for exploring the relationship from last night's sleep and next day physical activity, and from daytime physical activity to nighttime sleep.

Table 5.5 *Results of the multilevel models for exploring the effects of daytime physical activity on subsequent sleep*

Outcome	Predictor	Fixed coefficient	LRT -Log likelihood	LRT *P*- value	AIC
SQ	C	6.644	1594	n.a	3197.7
	C + Level of PA	6.649, -0.001	1594	0.971	3199.7
	C + Running	6.634, 0.006	1594	0.832	3199.6
	C + Walking	6.636, 0.001	1594	0.957	3199.7
	C + Standing	6.688, -0.011	1594	0.703	3199.5
	C + Sitting	6.407, 0.038	1594	0.243	3198.3
	C + Lying down	6.801, -0.042	1593	0.136	3197.5
SE	C	93.175	3010	n.a	6029.3
	C + Level of PA	93.198, -0.004	3010	0.978	6031.3
	C + Running	93.273, -0.069	3010	0.685	6031.1
	C + Walking	94.495, -0.264	3009	0.096	6028.5
	C + Standing	92.329, 0.212	3009	0.189	6029.6
	C + Sitting	91.610, 0.251	3009	0.167	6029.4
	C + Lying down	93.586, -0.11	3010	0.478	6030.8
TST	C	444.688	5092	n.a	10192.1
	C + Level of PA	467.986, -4.534	5089	0.028*	10189.3
	C + Running	451.531, -4.836	5089	0.021*	10188.8
	C + Walking	452.112, -1.488	5091	0.454	10193.5
	C + Standing	446.509, -0.456	5092	0.822	10194.1
	C + Sitting	434.681, 1.610	5091	0.474	10193.6
	C + Lying down	420.850, 6.441	5086.5	0.0008***	10183.0

Notes: LRT= Likelihood ratio test. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$. - Log likelihood= the negative log maximum likelihood. C= Constant. Level of PA= Level of physical activity. SQ= sleep quality. SE= Sleep efficiency. TST= Total sleep time. n.a= Not available.

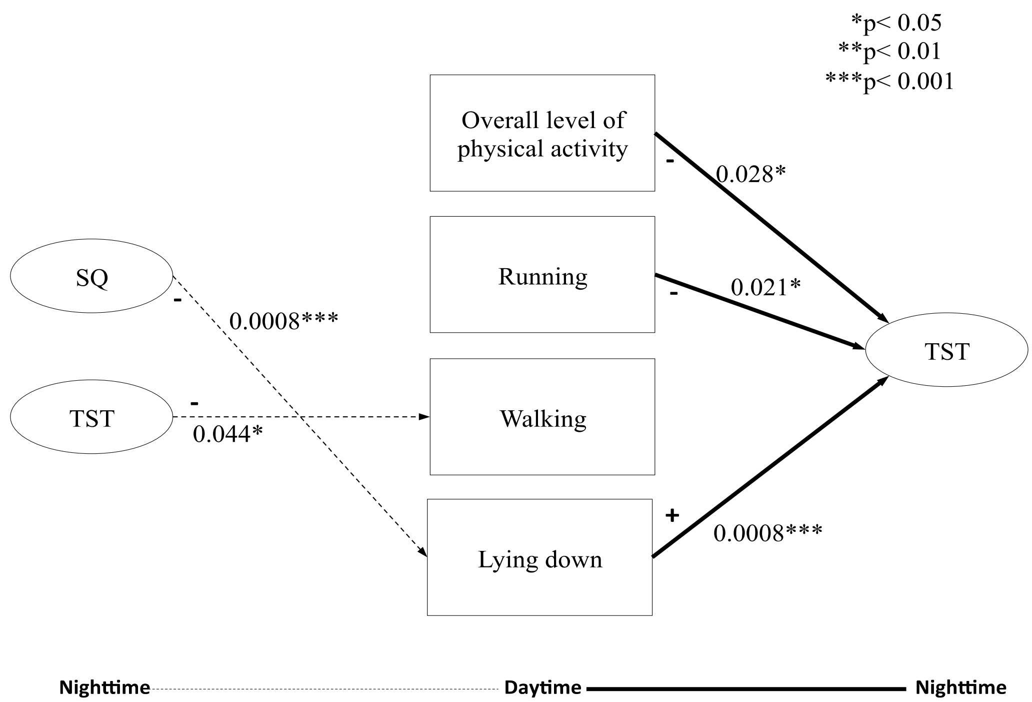

Figure 5.2 Results summary of the multilevel models for exploring the relationship from last night's sleep and next day physical activity (dotted arrows), and from daytime physical activity to nighttime sleep (solid arrows).
SQ= Sleep quality. TST= Total sleep time.
+/- = Indication of the relationship. "Nighttime"/ "Daytime"= Timeframe of sleep and physical activity. **p*< 0.05. ***p*< .01. ****p*< .001.

5.4 Discussion

Multilevel models were fitted to explore the within-person temporal relationship between different indices of nighttime sleep and daytime physical activity in 118 healthy young adults. The findings did not find significant associations between sleep and overall level of physical activity. However, there were significant associations between sleep and different types of physical activity. When physical activity was categorised by type, individuals who had worse sleep quality the previous night spent more time lying down the next day and, those who spent longer time lying down during the day had longer total sleep time on the subsequent night. Further, those who had shorter total sleep time spent more time walking the next day and those who spent less time on overall level of physical activity and running during the day had longer total sleep time the subsequent night. Although the findings reflect a bidirectional and temporal relationship between sleep and physical activity in healthy young adults, the findings suggest a possible different role for sleep quality and total sleep time in influencing physical activity the next day.

The significant associations of different types of sleep (i.e., sleep quality and total sleep time) and types of physical activity (i.e., walking, lying down) are consistent with the findings of the previous studies that examined within-person association between sleep and physical activity among individuals with and without bipolar disorder (McGlinchey et al., 2014) and pain-free older adults (Dzierzewski et al., 2014). However the findings of the present study did not find significant association between perception of poor/better sleep quality and overall level of physical activity. A possible explanation for this might be that the effect faded when all kinds of physical activity were aggregated. It is interesting to note that in the present study, poor sleep quality predicted subsequent sedentary behaviour that was lying down but not overall level of physical activity and dynamic physical activity (i.e., running). This may be explained by the fact that sedentary behaviours and dynamic physical activity could be influenced by qualitatively different factors. Using self-administered questionnaire, Burton, Turrell, Oldenburg, and Sallis (2005) conducted a survey to examine the relative contributions of psychological, social and environmental variables to different types of physical activity (e.g., walking, total activity, moderate- and vigorous- intensity physical activity) among 1827 adults aged 18 to 65 years old. They found that physical health, anticipated competitiveness, and time management barriers contributed more to the vigorous-intensity physical activity. Meanwhile the neighbourhood environment such as perceived safety and ambiance contributed more to walking. In addition, results from Schmid et al.'s study (2009) demonstrated that healthy individuals who experienced sleep impairment were more likely to lower the intensity of physical activity levels and reduce the daytime physical activity. Taken together, potentially different kinds of physical activity appear to systematically vary in terms of contexts, demands, or characteristics.

Surprisingly, the significant positive association between lying down and total sleep time is not expected. According to the Two-process Model of Sleep Regulation (Borbely, 1982), the homeostatic sleep drive is accumulated throughout the day. Lying down (i.e., a state of inactivity) during the day would weaken the homeostatic sleep drive and disrupt circadian rhythm such as decreasing in the light exposure and irregular of rest-activity cycles and physical activity (Van Someren & Riemersma-Van Der Lek, 2007; Youngstedt, Kripke, & Elliott, 2002). Severe reduction in homeostatic sleep drive and a shift in circadian rhythms could influence total sleep time (Dijk, Duffy & Czeisler, 2000). Gellis, Park, Stotsky, and Taylor (2014) reported that it was common among university students to have irregular sleep-wake schedule and use bed for activities other than sleep such as reading and watching television in bed. In addition, as a group, the characteristics of participants in the present study reflect typical sleep pattern of this age group with longer total sleep time (≥7 hours), higher sleep efficiency, shorter sleep onset latency and less awakenings during the night. Groeger et al. (2004) reported that individuals aged 16 to 24 years slept more than 7 hours every night. Hence, the long duration of total sleep time might be related with the participants' developmental sleep need following greater time spent lying down in the day (Hirshkowitz et al., 2015).

With regard to sleep efficiency, the findings indicated that sleep efficiency was not a significant predictor of daytime physical activity the next day and none of the daytime physical activity variables predicted sleep efficiency the subsequent night. This was unexpected, as sleep efficiency has been commonly considered an indicator of sleep continuity and correlated with subjective sleep quality (Akerstedt et al., 1994; Kaplan et al., 2017; Keklund & Akerstedt, 1997). This finding is contradictory to that of Lambiase et al.'s (2013), in which a significant temporal association between greater sleep efficiency (derived from actigraph) and greater physical activity the next day among older women was found. There are several possible explanations for the non-significant finding in the present study. First, it seems possible that there was a qualitative difference between different types of sleep indices (i.e., sleep efficiency, sleep quality, total sleep time). For example, perception of sleep quality might carry a stronger influence on physical activity the next day (Tang & Sanborn, 2014). Individuals may retrospectively perceive their sleep experience based on their feeling on waking in the morning such as feeling "unrefreshed" and "tired" which in turn decreases their subsequent physical activity. Argyropoulos et al. (2003) demonstrated that there was a significant relationship between perception of sleep quality and feelings on waking in 40 patients with depression. Second, the relationship between sleep efficiency and physical activity might be confounded by mood. McCrae et al. (2008) showed that nights with worse sleep quality were followed by days with more negative affect and less positive affect in older adults (aged ≥60 years). However, morning mood and morning pain were non-significant predictors in the temporal relationship between sleep and physical activity among heterogeneous patients with chronic pain (Tang & Sanborn, 2014). Smith et al. (2009) suggested that sleep impairment might interact with multiple mechanisms to influence physical activity. Further studies, which take mood, pain and other psychological variables such as tiredness, motivation and fatigue into account, will need to be undertaken.

Strengths and limitations

A key strength of this study is its daily process design that involved repeated monitoring of sleep and physical activity at specific times over seven days for time-lagged data analysis. This study was specifically designed for participants to monitor their sleep and physical activity in their own natural sleeping and living environment in which has the advantage for more ecological validity of the findings. Therefore participants were free to carry out their daily activity outside the controlled laboratory setting and did not require alteration of their daily activity and sleep. However, there are several limitations to this present study. First, although the advantage of paper-and-pencil physical activity diary was that it was inexpensive, easy to administer and easily accessible, the limitation was that it did not provide information or data on the hour of the day when the activities were performed continuously. In addition, it lacks of objectivity and precision. Future studies should consider using objective assessment in addition to subjective assessment to maximise the recording precision of the daily data over an extended time period with less intrusion and minimal discomfort for the participants. For example the use of a physical activity-monitoring recorder could help minimise participants' recall bias as it could automatically detect participants' movement. Second, the extent to which the results can be generalised to the clinical population such as patients with chronic pain or treatment seeking individuals remains to be determined in future research as the current study was carried out in healthy young adults drawn from a university setting. Nevertheless, it should be noted that the present sample reflected findings that were free from the influence of medical condition or medication.

Besides, physical activity pattern in pain-free individuals might be different from individuals with chronic pain (e.g., Spenkelink, Hutten, Hermens, & Greitemann, 2002; van den Berg-Emons et al., 2007). Spenkelink et al. (2002) found that patients with chronic low back pain demonstrated a lower physical activity level specifically in the evening compared to pain-free individuals. Tang and Sanborn (2014) also found that there was a gradual decline in physical activity from 4.00pm to 4.00am in a heterogeneous chronic pain sample. But it is important to note that the gradual decline was observed within the context of human circadian rhythm and there was no pain-free control group as comparison. Finally, whilst a minimum of 7 days physical activity monitoring is a substantive period of time to ensure a reliable estimate of regular physical activity pattern (Trost, Pate, Freedson, Sallis, & Taylor, 2000), a longer monitoring period would be important for future study to allow for adaptation particularly if it is being conducted in clinical patients as they could have different physical activity pattern such as increased activity fluctuations compared to healthy individuals (Verbunt, Huijnen, & Seelen, 2012). Patients with chronic pain's daily physical activity levels have often been described as a saw-tooth pattern (Hasenbring et al., 2006; Verbunt et al., 2012). The "saw-tooth pattern" refers to the huge between-day variation in physical activity among patients with chronic pain.

Conclusion

In conclusion, the findings of the present study highlight the presence of a potential temporal relationship between sleep and physical activity at the within-person association. Specifically, the findings revealed that nights of worse sleep quality were followed by days of greater time spent on lying down, which subsequently followed by nights of longer total sleep time. However these findings may need to be verified with the objective measure. The next crucial step is to replicate the present study in people with chronic pain and correct the limitations discussed. These methodological improvements will be discussed in Chapter 6.

Chapter 6

Study 4 - A Daily Process Study On The Association Between Sleep And Physical Activity In Patients With Chronic Pain

6.1 Introduction[4]

The daily process study in this chapter is a replication and extension of the daily process study presented in Chapter 5 with a chronic pain patient sample and a longer length of assessment period (i.e., 14 days). In addition to subjective assessment of sleep and physical activity using diaries, the current study included objective measurements of sleep (i.e., actigraphy) and physical activity (i.e., Physical activity monitoring sensor-PAMSys). These objective assessments further strengthen the methodological rigour in the present study specifically in assessing types, time and duration of different types of physical activity. Furthermore, the use of objective assessments for collecting data over a long period of time could reduce recall bias, minimise participants' burden as it is non-intrusive and provide home monitoring and ecological validity. An additional aim of the current study was to investigate the possible role of pain and other psychological variables in determining subsequent physical activity. The variables of interest were pain, mood, tiredness, fatigue, sleepiness, energy level, body condition, motivation to accomplish tasks, confidence to get things done and management of pain on physical activity. These psychological variables were proposed in this present study based on the

[4] The introduction of Study 4 is kept short, as the study is a replication and extension of Study 3 (presented in Chapter 5). Most of the past studies related with Study 4 and Study 3 have been discussed in Introduction of Chapter 5 (see 5.1).

cognitive-behavioural model of insomnia (Harvey, 2002) and the fear avoidance model (Vlaeyen & Linton, 2000). The current study explored the roles of psychological variables because various psychological variables may interact with sleep to impact on daytime physical activity (Smith et al., 2009).

Different from Chapter 5, the present study used cold pressor task (CPT) to evaluate the participants' pain thereshold. The CPT is a standardised quantitative sensory testing (QST) for experimentally inducing pain (Baeyer, Piira, Chambers, Trapanotto, & Zeltzer, 2005). Studies have shown that patients with chronic pain specifically individuals with fibromyalgia are sensitive to pain even light touch to the skin could be perceived as painful (Desmeules et al., 2003; Flor, Diers, & Birbaumer, 2004). Using QST, Desmeules et al. (2003) found that patients with fibromyalgia had significantly lower cold ($p < 0.001$) and heat ($p = 0.005$) pain threshold than the healthy control group. Moreover, sleep disturbance increases sensitivity to pain through impairment in the central pain modulation (CPM; Lautenbacher, Kundermann, & Krieg, 2006; Smith et al., 2007). However, it was not the focus of the present study to examine CPM in detail. The aim of administering CPT in the present study was just to characterise the participants.

6.2 Methods

6.2.1 Design

A daily process study was conducted with 61 participants with chronic pain to examine the temporal association between sleep and physical activity. Figure 6.1

illustrates the design of the study, which required the participants to keep a sleep diary about their sleep and daily diary about their psychological variables, and to wear an actigraphy and physical activity monitoring sensor for 14 days, in their natural living and sleeping environment. The sleep diary asked participants to record the subjective estimate of sleep (see 6.2.1) in which the participants completed the sleep diary in the morning on waking based on the sleep they had on the previous night. The daily diary asked participants to record their psychological variables (i.e., pain, mood, tiredness, fatigue, sleepiness, energy level, body condition, motivation to accomplish tasks, confidence to get things done and management of pain) at different times of the day (i.e., morning [Diary 1], bedtime [Diary 3] and midpoint between Diary 1 & 3). Objectively, actigraphy was used to measure sleep during the night and overall level of physical activity during the day, together with a Physical Activity Monitoring Sensor (PAMSys) that assessed time spent on different types of physical activity (running, walking, standing, sitting, lying down) during the day. This design is identical to the design of the study in Chapter 5 (see 5.2.1). However, there were differences in term of participants, duration and additional measures in this study. First, the duration of this study was extended to 14 days instead of 7 days. Second, actigraphy was used in addition to the sleep diary to measure sleep objectively. Third, the physical activity diary in Chapter 5 (see 5.2.5) was replaced by actigraphy and PAMSys to record the overall level of physical activity and time spent on different types of activity during the day. Fourth, a daily diary was added in this study to measure psychological variables at different times of the day. The data collected were therefore time-specific and can be used to explore the temporal effect of sleep on next day physical activity (see dotted arrows in Figure 6.1) and the effect of physical activity on the subsequent sleep (see solid arrows in Figure 6.1). The data were also used to investigate the temporal effect of psychological variables on the subsequent physical activity (see dotted arrows in Figure 6.1) and the temporal effect of the overall level of physical activity on the presleep pain and presleep mood. The design of the present study focused on the within-person temporal association between sleep, psychological variables and physical activity in people with chronic pain.

In addition, a Cold Pressor Task (CPT) was used to measure participants' pain threshold (on Day 8, see Figure 6.1). This task involved the participants submerging their hands (up to about 5cm from the wrist) in 4° Celsius cold water until they feel the cold pain and retrieve their hand from the water. The data from the CPT was used to characterise participants in terms of pain characteristics.

The study protocol had received full ethical approval from NHS South Birmingham Research Ethics Committee (Reference number: 15/WM/0171; Appendix 15) and Department of Psychology Research Ethics Committee, University of Warwick.

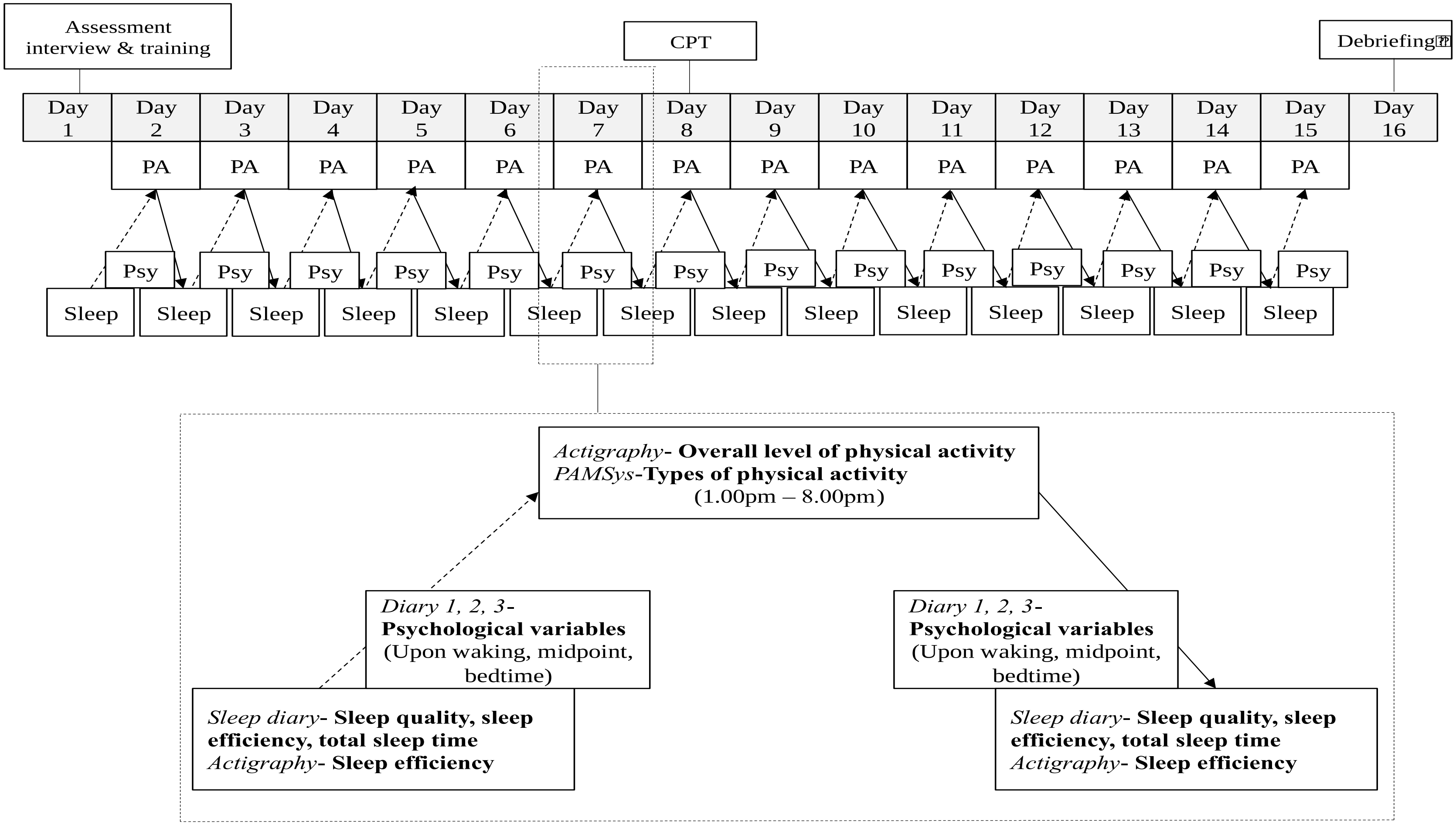

Figure 6.1 Study design and variables assessed by sleep diary (i.e., sleep quality, sleep efficiency, total sleep time), actigraphy (i.e., sleep efficiency, overall level of physical activity), PAMSys (i.e., types of physical activity: running, walking standing, sitting, lying down) and Diary 1, 2, 3 (i.e., psychological variables: pain, mood, tiredness, fatigue, sleepiness, energy level, body condition, motivation to accomplish tasks, confident to get things done, management of pain). PA= Physical activity. Psy= Psychological variables. CPT= Cold pressor task. Dotted arrow= Sleep predicted physical activity; Psychological variables predicted physical activity. Solid arrow= Physical activity predicted sleep; Physical activity predicted psychological variables.

6.2.2 Sample size

See 5.2.2 in Chapter 5 for sample size estimation. The sample size of 51 participants in the present study will give 714 observations and sufficient power to absorb likely data attrition and for modeling the within-person relationship between sleep and physical activity and vice versa, and between psychological variables and physical activity.

6.2.3 Participants

Participants of the present study were recruited through advertisement circulated within local pain patients support groups (e.g., Coventry Fibromyalgia Support Group), Warwick Sleep and Pain Laboratory database (i.e., the database consisted of subject panel with individuals with (and without) chronic pain who registered in volunteering for ongoing research at the laboratory), Pain Management Clinic and Department of Rheumatology University Hospital Coventry and Warwickshire (UHCW), and recruitment advertisement posted at the University of Warwick's Research Participation webpage. Participants were included in the study if they were (1) aged between 18 and 65 years, (2) English speaking, (3) had non-malignant chronic pain for at least 6 months (e.g., fibromyalgia, chronic back pain, arthritis). The diagnoses were confirmed by self-report from the participants. Potential participants excluded from the study were those who (1) had acute pain of <6 months as a results of surgery or injury, (2) had severe psychiatric illness (e.g., psychosis), neurological conditions (e.g., dementia) or life threatening medical condition (e.g., HIV, cancer) that would prevent the provision of informed consent and full participation in the study, (3) had any other known sleep disorders that might explain sleep disturbance (e.g., sleep apnoea, restless leg syndrome, narcolepsy), however those who reported to have insomnia were not excluded, (4) being pregnant or are new parents, (5) enrolled in a clinical study/ drug trial or is scheduled to receive an injection/ a surgery during the duration of the study, (6) enrolled in an insomnia/ pain management programme or is scheduled to start such treatment during the duration of the study (e.g., cognitive-behaviour therapy for Insomnia), (7) shift worker with irregular sleep pattern, (8) had drug and/or alcohol misuse, (9) wheelchair dependent. Five additional exclusion criteria were also specifically included to minimise the risk of reaction to the pain with a stress response during CPT (Baeyer et al., 2005). The criteria were those who (1) had a cardiac pacemaker and/or history of cardiovascular disorder, (2) had history of fainting or seizures, (3) had history of frostbite, Reynaud's phenomenon, (13) had fracture of limb to be immersed, (14) open cut or sore on hand to be immersed.

Figure 6.2 presents the recruitment flow diagram. A total of 215 potential participants were invited to take part in the study. Of 215 potential participants, 100 did not respond to the invitation and 19 were not able to give commitment to the study. Of the 96 individuals who responded to the invitation, 21 did not meet the study inclusion criteria. Of the 75 eligible participants who were invited to the assessment session, 9 did not show up to the session and 5 declined to take part in the study. A total of 61 eligible participants who were interviewed, assessed and entered into the study, 10 withdrew halfway through the study (7 too busy to complete the monitoring, 1 lost communication with the researcher and did not return the monitoring devices and 2 had developed skin irritation as a result of wearing the actigraphy and PAMSys. Hence the final sample for data analysis consisted of 51 participants with chronic pain.

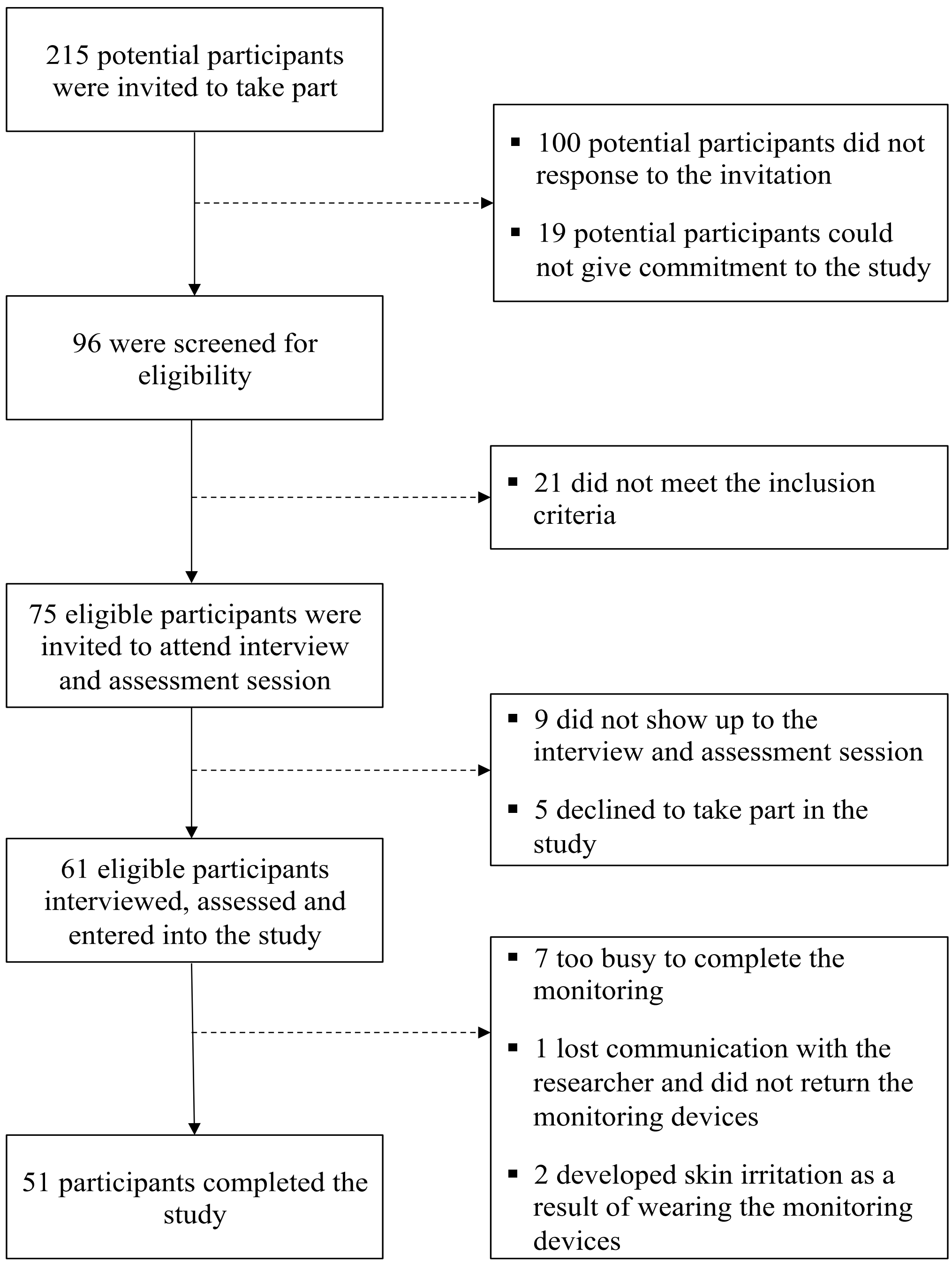

Figure 6.2 Recruitment flow diagram

6.2.4 Procedure

All potential participants were invited to take part in the study and were provided with detailed information of the study. Individuals who expressed interest to take part in the study were screened for eligibility based on the inclusion and exclusion criteria (see section 6.2.2). Eligible participants were invited to attend an assessment interview at the Warwick Sleep and Pain Laboratory. Although the presence of insomnia was not an inclusion criterion to the study, Duke Structured Interview Schedule for DSM-V and International Classification of Sleep Disorders (ICSD-3) was administered to the participants who had insomnia/ sleep complaints. This additional assessment interview was to confirm the insomnia symptoms met the diagnostic criteria and to rule out psychiatric problem, sleep disorders or other medical illness that could account for participant's sleep disturbance.

Following the assessment interview, written informed consent was taken from the eligible participants. Eligible participants were also asked to complete a set of questionnaire at their home and bring the completed questionnaire to the laboratory. The questionnaires consisted of items asking about participants' demographics (age, sex, body mass index, ethnicity, employment status), anxiety and depression symptoms, fatigue, sleep problem, chronotype, daytime sleepiness, negative belief and attitude about sleep, pain related dysfunctional beliefs and attitudes about sleep, pain severity and interference, fear of movement/(re)injury, and pain-related activity patterns (See section 6.2.5). These questionnaires were used to describe and characterise the participants.

Prior to starting the monitoring procedure, participants were given one-to-one training session on how to answer each item on the paper-and-pencil sleep diary and daily diary and how to use/wear the actigraphy and PAMSys. In addition, participants were given a training manual that described the monitoring procedures and use of devices in the study (see Appendix 20), a monitoring schedule that described the particular timing of the task that they have to do (see Appendix 21) and a written guidelines that explained what was being asked for each item of the diaries (see Appendix 23). These materials were designed to be a self-reference tool for when they were at home so they could refer to the specifics, if necessary. The purpose of the training was to ensure that the participants would be able to complete the monitoring task efficiently, the diaries correctly, and familiarise with operating of the monitoring technologies (i.e., actigraph and PAMSys). Thus this training could minimise missing data due to human or technical failure. During the multilevel models involving actigraphy data, 6 participants were excluded from the analysis due to incomplete data collection of one or two nights (caused by technical failure). They were sent home to start the data collection once they had demonstrated understanding of the task by completing one set of the training diary and capability in using actigraph and PAMSys.

The data collection process was 14 days long and 51 participants completed 14 days of monitoring. During this period, to minimise unmeasured or unwanted confounders that might influence the findings, participants were advised not to change their usual sleep-wake pattern, typical daily activity routine, use of medication and consumption of coffee/ tea, alcohol and/or tobacco during the study. They were asked to keep the same regimen because to control for the influence of medications use on the findings. They were asked to complete the sleep diary every morning on waking and daily diary every morning on waking (Diary 1), midpoint between Diary 1 and 3, and evening at bedtime (Diary 3). Specifically they were asked to complete the diaries within 30 minutes of their get up time, 30 minutes within the midpoint time of Diary 1 and 3, and 30 minutes within their bedtime. They were asked to wear the PAMSys on the chest (just under the pectoral muscles; see Appendix 20) continually during the day and an actigraphy on non-dominant wrist continually during the day and night, except when bathing, showering, swimming or coming into any contact with water as it was not water resistant. Participants were also asked to press an event-marker button on the actigraphy to mark specific events (e.g., bedtime and wake up time).

After 7 days of data collection (on Day 8), participants came back to the laboratory for the second time to take part in the CPT, maintenance of the monitoring devices (i.e., changing the battery) and discuss with the researcher any difficulties or problems encountered during the monitoring. Then they went home and carried on the monitoring for the remaining days. On Day 16, participants came back to the laboratory for the final time to return the sleep diary, daily diaries and monitoring devices. Participants were debriefed on their participation (i.e., given the opportunity to express concerns about the study, and asked if they had any problems as a result of taking part in the study). Participants were reimbursed £20 for their travel expenses.

6.2.5 Measures

Sleep diary

Sleep was assessed using the Consensus Sleep Diary (CSD, Carney et al., 2012; see Appendix 22). See sleep diary section in 5.2.5 (Chapter 5) for details about the sleep diary. As described in 5.2.5 (Chapter 5), the key sleep variables derived from the sleep diary data were sleep quality, sleep efficiency and total sleep time.

Actigraphy

Objective estimate of sleep during the night was measured using actigraphy. It is user friendly and non-intrusive sleep assessment. It is a wristwatch-like device that is equipped with piezoelectric accelerometer to detect movements in all directions as it operates based on the principle of people make more movement during wake and less movement during sleep (Ancoli-Israel et al., 2003; The actiwatch activity monitoring system User Manual). Participants were required to wear the actigraphy on the non-dominant wrist continually and only taken off when bathing, swimming or coming into any contact with water. In addition, participants were asked to press the event marker on the actigraphy to record bedtime (i.e., when they were trying to fall asleep/ when they switched off the light and ready to sleep) and get up time (i.e., when they woke up the next morning/ final awakening in the morning). This additional behavioural measure aimed to increase the accuracy in the estimation of sleep onset and wakefulness, as actigraphy was not able to detect the precise moment of sleep onset latency in individuals with quiet wakefulness. The Data from the actigraphy was downloaded for analysis using the software Actiwatch Activity & Sleep Analysis 5 (Version 5.43, Cambridge Neurotechnology Ltd). Actigraphy has been validated and reviewed as acceptable objective measure in various clinical population including patients with insomnia (Lichstein et al., 2006). Actigraphy-sleep efficiency index (A-SE) was selected as the key sleep variable to be included as predictor and outcome in the multilevel modeling. A-SE is the percentage of time spent asleep whilst in bed (The actiwatch activity monitoring system User Manual).

Actigraphy was also used to assess the overall level of physical activity. The timeframe of physical activity data included in the analysis was from 1.00pm to 8.00pm. The timeframe was set after taken into consideration each participant's bedtime and get up time. This was to ensure a precise chronological order of the events (e.g., physical activity occurred during post-sleep).

Physical activity monitoring sensor (PAMSys)

Time spent on different types of physical activity (i.e., running, walking, standing, sitting, lying down) was assessed using PAMSys. PAMSys (by Biosensics LLC) is a lightweight, wearable motion sensor affixed to the body with a chest strap (just under the pectoral muscles). It was equipped with a single triaxial accelerometer. PAMSys was worn continually round-the-clock except during sleep at night and when taking shower, bathing or coming into any contact with water. Data from the PAMSys was downloaded for analysis using the software PAMWare (Version 1.71 Biosensics LLC). PAMSys has been used in numerous studies (e.g., Alamri et al., 2014; Najafi, Crews, & Wrobel, 2010).

Running, walking, standing, sitting and lying down were chosen as the key variables derived from the PAMSys data to be included as predictors and outcomes in the multilevel modeling. These activities provided the types of individual's daily activity and the duration they spent on those activities. The timeframe of physical activity data included in the analysis was from 1.00pm to 8.00pm.

Daily diary

Psychological variables were assessed using daily diary at different times of the day (see Appendix 23). The paper-and-pencil daily diary comprised three diaries, which were Diary 1 to be completed upon waking in the morning, Diary 2 to be completed at midpoint between Diary 1 and Diary 3, and Diary 3 to be completed at bedtime. The daily diary contained 11 items that were repetitive in all three diaries and the response scale was a numeric rating scale (0-10). It contained questions asking the participants to rate the current level of pain ("How would you rate the current level of pain"?; from 0= No pain to 10= Pain as bad as it could be) and mood ("How you rate your current mood?"; from 0= Very bad to 10= Very good). The participants were also asked about their tiredness ("To what extent do you feel tired?"; from 0= Not at all to 10= Very much so), fatigue ("To what extent do you feel sleepy right now?"; from 0= Not at all to 10= Very much so), sleepiness ("To what extent do you feel sleepy?"; from 0= Not at all to 10= Very much so), energy level ("How would you rate your current energy level?"; from 0= Very low to 10= Very high) and body condition ("How would you rate your current body condition?"; from 0= Fragile/ weak to 10= Healthy/ strong). In addition, the participants were asked to rate the motivation level ("To what extent do you feel motivated to accomplish tasks right now?"; from 0= Not at all to 10= Very much so), the confident level ("To what extent do you feel confident that you can get things done?"; from 0= Not at all to 10= Very much so), the management of pain right now and later ("To what extent do you feel you can manage your pain right now?", "To what extent do you feel you can manage your pain later?"; from 0= Very poorly to 10= Very well). The daily diary minimised recall bias as the participants recorded their psychological changes throughout the day.

Cold pressor task (CPT)

Pain threshold was measured using CPT. The CPT is a standard quantitative sensory testing to induce experimental pain in the laboratory. The task involved the participants submerging their hands (up to about 5cm from the wrist) in 4° Celsius cold water until they feel the cold pain and immediately retrieve their hand from the water. Participants were also reminded to put their hand in the water without touching the bottom of the tank. The water tank was made of stainless steel and contained approximately 18 litres of cold water. The water was maintained at 4° Celsius using immersion thermostat and cooler (model: T100 by Grant Instrument Cambridge Ltd). Pain threshold was defined as the duration of immersion (in seconds) from the time the hand was immersed in the water to the time that pain was first reported (Baeyer et al., 2005). Pain rating was also taken by asking participants "*In a scale 0 to 10, with 0= no pain at all to 10= pain as bad as it could be, how would you rate your pain when you* *retrieve your hand?*". There were two trials, in the first trial, participants immersed their non-dominant hand and followed by dominant hand in the second trial. Prior to starting the CPT, participants were asked to put their hand in the warm water (room temperature) for few seconds to standardise initial hand temperature across participants. In addition, to minimise the experimenter effect, researcher stood behind the participant during the CPT whilst recording the trial (i.e., time in seconds) using a stopwatch.

Questionnaires

The questionnaire (see Appendix 19) consisted of measures that assess the participants' demographics (age, sex, body mass index, ethnicity, employment status), anxiety and depression symptoms using the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983), fatigue using the Multidimensional Fatigue Inventory (MFI; Smets et al., 1995), sleep problem using the Insomnia Severity Index (ISI; Bastien et al., 2001), chronotype using the Morningness-Eveningness Questionnaire (MEQ; Horne & Ostberg, 1976), daytime sleepiness using the Epworth Sleepiness Scale (ESS; Johns, 1991), negative belief and attitude about sleep using Dysfunctional Beliefs and Attitudes about Sleep (DBAS-16; Morin et al., 2007), pain related dysfunctional beliefs and attitudes about sleep using the Pain-Related Beliefs and Attitudes about Sleep scale (PBAS; Afolalu et al., 2016), pain severity and interference using the Brief Pain Inventory (BPI; Cleeland & Ryan, 1994), fear of movement/(re)injury using the Tampa Scale for Kinesophobia-11 (TSK-11; Woby, Roach, Urmston, & Watson, 2005), and pain-related activity patterns using the Patterns of Activity Measure-Pain (POAM-P; Cane, Nielson, McCarthy, & Mazmanian, 2013).

Hospital Anxiety and Depression Scale (HADS): The HADS was used to assess symptoms of anxiety and depression. It consists of 14 items that asked participants to rate the severity of their symptoms during the past week on a 4-point likert scale (0-3). The scores range from 0 to 21 for each subscale for anxiety and depression and are interpreted as normal range (0-7), mild (8-10), moderate (11-14) and severe (15-21). Higher scores indicate greater symptom severity. The HADS has shown to have good internal consistency (Cronbach α = 0.41 to 0.76) and concurrent validity (correlations between clinician interview ratings and patient ratings of anxiety: r = 0.54 and depression: r = 0.79).

Multidimensional Fatigue Inventory (MFI): The MFI is a 20-item self-report instrument that was used to assess fatigue. Each item is rated on a 5-point likert scale from 1 (yes, that is true) to 5 (no, that is not true). The total score ranges from 20 to 100 with higher score suggesting greater fatigue. The MFI has demonstrated good internal consistency (Cronbach α > 0.8) and convergent validity (correlation with visual analog scale: r = 0.23 - 0.77).

Insomnia Severity Index (ISI): The ISI was used to assess sleep problem. It comprises 7 items that asked participants to rate their sleep patterns in the last month on a 5-point likert scale from 0 (not at all) to 4 (very much). The total score ranges from 0 to 28 that was interpreted as "0-7= no clinically significant insomnia", "8-14= subthreshold insomnia", "15-21= clinically moderate insomnia" and "22-28= clinically severe insomnia". The ISI demonstrated acceptable level of internal consistency (Cronbach α = 0.76 – 0.78) and concurrent validity (correlation with polysomnography variables: r = 0.07–0.45 and correlation with sleep diary variables: r = 0.32–0.91).

Morningness-Eveningness Questionnaire (MEQ): The MEQ was used to assess chronotype or circadian rhythms. The MEQ contains 19 questions assessing participant differences in rise time and bedtimes, alertness and time an individual prefers to perform various activities. The score from each item was added together to sum up a total score. The scores range from 16 to 86 and are categorised into five different chronotypes, which are "Definitely morning type (70-86)", "Moderately morning type (59-69)", "Intermediate (42-58)", "Moderately evening type (31-41)", and "Definitely evening type (16-30)". The MEQ has demonstrated adequate internal consistency (Cronbach α = 0.86) and concurrent validity (correlations with oral temperature variables: r = 0.37- 0.79).

Epworth Sleepiness Scale (ESS): The ESS is an 8-item self-report scale that was used to measure general level of daytime sleepiness in common situations of daily living. Participants were asked to respond to each item on a 4-point scale from 0 = would never doze to 4 = high chance of dozing. The total scores range from 0 to 24 and are categorised into "0-7 = unlikely", "8-9 = average amount of daytime sleepiness", "10-15 = excessive sleepiness depending on situation and should consider seeking medical attention", and "16-24 = excessive daytime sleepiness and seeking medical attention". The ESS has shown to have acceptable internal consistency of Cronbach α =

0.88 and concurrent validity (correlation with sleep latency from polysomnography r = -0.379).

Dysfunctional Beliefs and Attitudes about Sleep (DBAS-16): The DBAS-16 was used to assess negative belief and attitude about sleep. It comprises 16-item that asked participants to rate to what extent they disagree or agree with each statement on an 11-point scale from 0 (Strongly disagree) to 10 (Strongly agree). A higher score on the DBAS-16 suggests that participant endorses more intense and more frequent dysfunctional belief and attitude about sleep. THE DBAS-16 has shown good internal consistency (Cronbach α = 0.77) and concurrent validity (correlation with ISI: r = 0.45).

Pain-Related Beliefs and Attitudes about Sleep (PBAS): The PBAS was used to assess pain related dysfunctional beliefs and attitudes about sleep in chronic pain population. It contains 10 items that asked participants to rate to what extent they disagree or agree with each statement on an 11-point scale from 0 (Strongly disagree) to 10 (Strongly agree). The total score was calculated as the average score of all items with a higher average score suggesting stronger beliefs that pain and sleeplessness related. The PBAS has shown to have good internal consistency (Cronbach α = 0.84) and concurrent validity (correlation with DBAS-16: r = 0.65; correlation with DBAS-16: r = 0.65; correlation with the Anxiety and Preoccupation about Sleep Questionnaire (APSQ): r = 0.57).

Brief Pain Inventory (BPI): The BPI was used to assess the severity of the pain and pain related interference. It comprises 4 items that measure the severity of the pain and 7 items that measure pain related interference. On the pain severity subscale, the total score was calculated as the average of the 4 items. Higher score indicates greater severity of pain. On the pain related interference subscale, participants were asked to rate to what extent pain interferes with their general activity, mood, walking ability, work both inside and outside home, relations with people, sleep and enjoyment of life on an 11-point scale from 0 (does not interfere) to 10 (Completely interfere). The total score of pain related interference subscale was calculated by as the average of the 7 items. The PBAS has demonstrated good internal consistency (Cronbach α = 0.88) and concurrent validity (correlation with the Roland-Morris Disability Questionnaire: r = 0.57).

Tampa Scale for Kinesophobia-11 (TSK-11): The TSK-11 is a self-report questionnaire administered to measure fear of movement/(re)injury. It contains 11 items that asked participants to rate each item on a 4-point scale from 1 (strongly disagree) to 4 (strongly agree), with higher scores indicating greater fear of movement/(re)injury. The TSK-11 has shown acceptable internal consistency (Cronbach α = 0.79) and concurrent validity (correlation with Roland disability questionnaire: r = 0.51; correlation with Pain visual analogue scale: r = 0.27).

Patterns of Activity-Pain (POAM-P): The POAM-P was used to assess pain-related activity patterns of avoidance, overdoing, and pacing in chronic pain population. It contains 30 items (i.e. three subscales namely avoidance, overdoing and pacing with 10 items on each subscale) that asked participants to rate the extent to which each item described how they usually performed their daily activities using a 5-point likert scale from 0 (not at all) to 4 (all the time). The POAM-P has been shown to have good internal consistency (Cronbach α = 0.86 – 0.94) and concurrent validity (correlation with Tampa Scale for Kinesophobia: r = -0.26 – 0.42; correlation with Coping Inventory-Pacing Scale r = -0.02 - 0.62).

6.2.6 Data analysis

The statistical software R (https://www.rstudio.com/products/rstudio) was used to analyse data. There were four sources of data in the study, which were from the questionnaire, CPT, sleep and daily diaries, and monitoring devices (i.e., actigraphy and PAMSys). Data from the questionnaire and CPT were analysed using descriptive statistics to characterise the participants, whereas data from the sleep and daily diaries and monitoring devices were fit with multilevel models (Field, Miles & Field, 2012).

Descriptive statistics

Descriptive statistics on the questionnaire data were used to characterise the participants in the study. Frequencies and percentages were presented for categorical variables, while means and standard deviations were reported for continuous variable.

Multilevel models

The analysis method was identical to that described for multilevel models in Chapter 5. Four sets of analyses were run: (1) to examine the effect of sleep on physical activity the following day, (2) to examine the effect of physical activity on the subsequent sleep, (3) to examine the effect of psychological variables upon waking in the morning on the subsequent physical activity, (4) to examine the effect of overall level of physical activity on the subsequent pre-sleep pain and mood.

For the first analysis, to examine the within-person temporal association between sleep (i.e., sleep quality, sleep efficiency, and total sleep time as the predictors) and physical activity the following day (i.e., overall level of physical activity, running, walking, standing, sitting, and lying down as the outcome variables), the daily monitoring data were pooled together from 51 participants, generating an aggregate data set of 714 observations across 14 days. However for actigraphy-sleep efficiency, the data were pooled together from 45 participants due to incomplete data from actigraphy (i.e., the incomplete data due to technical failure which resulted in missing data of one or two nights of actigraphic data), generating data set of 630 observations across 14 days. The multilevel models built in the present study considered variations in the relationship between sleep and physical activity at the "Day" level (Level 1), the "Week" level (Level 2), and the "Participant" level (Level 3). Altogether, 36 models were developed and analysed (i.e., 6 sleep predictors for each of the 6 physical activity outcome variable). See details in Multilevel models of Data Analysis section- 5.2.6 (Chapter 5).

In the second analysis, to investigate the within-person temporal link between physical activity during the day (i.e., overall level of physical activity, running, walking, standing, sitting, and lying down as the predictors) and subsequent sleep (i.e., sleep quality, sleep efficiency, total sleep time and actigraphy-sleep efficiency as the outcome variables), the daily monitoring data were pooled together from the same pool of participants, generating an aggregate data set of 663 observations (and 585 for actigrpahy-sleep efficiency) across 13 days. Altogether, 28 models were developed and analysed (i.e., 7 physical activity predictors for each of the 4 sleep outcome variable).

In the third analysis, to investigate the within-person temporal link between psychological variables (upon waking; i.e., pain, mood, tiredness, fatigue, sleepiness, energy level, body condition, motivation to accomplish tasks, confident to get things done, management of pain right now, and management of pain later as the predictors) and subsequent physical activity during the day (i.e., overall level of physical activity, running, walking, standing, sitting, and lying down as the outcome variables), the daily monitoring data were pooled together from the same pool of participants, generating an aggregate data set of 714 observations across 14 days. Altogether, 72 models were developed and analysed (i.e., 12 predictors for each of the 6 physical activity outcome variable)

In the fourth analysis, to investigate the within-person temporal link between the overall level of physical activity (as the predictor variable) and subsequent pre-sleep pain and mood (as the outcome variables), the daily monitoring data were pooled together from the same pool of participants, generating an aggregate data set of 663 observations across 13 days. Altogether, 4 models were developed and analysed (i.e., 2 predictors for each pre-sleep pain and mood outcome variable).

6.3 Results

6.3.1 Participant characteristics

Table 6.1 presents the demographics, pain, sleep and psychological characteristics of the participants. Participants in the present study had a mean age of 37.16 years (SD= 14.77) and BMI of 25.58 (SD= 6.42). The participants were largely female (74.5%) and white (62.7%). Approximately 31.4% of the participants were studying full-time, 25.5% were on full-time employment and 25.5% were on sick leave/ medically retired/ retired/ not working.

Nearly half of the participants (47%) reported experiencing back pain, fibromyalgia (21.5%), knee pain (11.7%), neck pain and headache (5.9%), nerve damage (3.9%), shoulder and neck pain (3.9%), rheumatoid arthritis (2%), joints pain (2%) and leg-feet pain (2%). The participants reported an average pain durations of 10.85 years (SD= 8.73), pain severity of 4.89 (1.65) and pain interference of 5.21 (SD= 2.23) on the BPI. Approximately 19.7% of the participants took non-steroidal anti-inflammatory drugs (NSAIDs) at the time of the study. The mean score for TSK was 20.43 (SD= 8.05) indicating fear of movement or (re)injury whereas for avoidance, overdoing and pacing patterns of activity (POAM-P) were 20.43 (SD= 8.05), 26.12 (SD= 6.72) and 21.35 (SD= 9.02) respectively. The participants' score on the subscales of POAM-P were lower on avoidance, higher on overdoing and lower on pacing than participants' score in Cane et al.'s study (2013).

As a group, the mean ISI score was 12.16 (SD= 8.37) suggesting subthreshold insomnia with 35.3% of them had insomnia of moderate severity and 11.8% had severe insomnia. Their circadian rhythm tendency scores on the MEQ showed that more than half of the participants (58.8%) were “intermediate type”, 19.6% were “moderately evening type”, 15.7% were “moderately morning type”, 3.9% were “definitely evening type” and 2% were “definitely morning type”. Their mean scores on the ESS was 9.82 (SD= 5.23) indicating that participants were most likely getting enough sleep. However their scores were just slightly below the cut-off 10 for probable conditions suffering from excessive daytime sleepiness. Meanwhile their means score on the DBAS-16 (5.19, SD= 1.76) and PBAS (5.49, SD= 2.39) were moderate, suggesting to some extent they held endorsement of negative belief and attitude about sleep and maladaptive belief and attitude about the interaction between sleep and pain.

Their mean score on the HADS-Anxiety was 8.69 (SD= 3.69) and HADS-Depression was 6.82 (4.44) indicating mild and normal symptoms based on the suggested cut-off (8 and above) for probable cases of anxiety and mood disorder. Meanwhile their level of fatigue on MFI was 64.16.

Table 6.1 *Participants' characteristics*

		n= 51	%
Demographics characteristics			
Age (19-65, in years)		37.16 (14.77)	
Body mass index		25.58 (6.42)	
Sex	Male	13	25.5
	Female	38	74.5
Ethnic origins	White	32	62.7
	White Irish	0	0
	Asian or Asian British: Chinese	11	21.6
	Asian or Asian British: Indian	3	5.9
	Asian or Asian British: Pakistani	0	0
	Asian or Asian British: Asian other	2	3.9
	Black or Black British	1	2
	British mixed	0	0
	Other	2	3.9
Employment status	Full-time employment	13	25.5
	Part-time employment	7	13.7
	On sick leave/ medically retired/ retired/ not working	13	25.5
	Full-time studying	16	31.4
	Other	2	3.9
Pain characteristics			
Pain complaints	Back Pain	24	47
	Fibromyalgia	11	21.5
	Knee pain	6	11.7
	Neck pain and headache	3	5.9
	Nerve damage	2	3.9
	Shoulder and neck pain	2	3.9
	Rheumatoid arthritis	1	2
	Joints pain	1	2
	Leg-feet pain	1	2
Pain duration (in years)		10.85 (8.73)	
BPI	Pain severity	4.89 (1.65)	
	Pain interference	5.21 (2.23)	
TSK-11		24.98 (6.89)	
POAM-P	Avoidance	20.43 (8.05)	
	Overdoing	26.12 (6.72)	
	Pacing	21.35 (9.02)	

Table 6.1 (continued) *Participant characteristics*

Medications*	Analgesics	11	18
	Antidepressants	10	16.4
	Anticonvulsants	3	4.9
	Benzodiazepine	1	1.7
	Non-steroidal anti-inflammatory drugs (NSAIDs)	12	19.7
	Opiod pain medication	10	16.4
	Tricyclic antidepressants	8	13.1
	Other	6	9.8
Sleep characteristics			
ISI		12.16 (8.37)	
	No clinically significant insomnia	15	29.4
	Subthreshold insomnia	12	23.5
	Moderate severity	18	35.3
	Severe	6	11.8
MEQ	Definitely evening type	2	3.9
	Moderately evening type	10	19.6
	Intermediate type	30	58.8
	Moderately morning type	8	15.7
	Definitely morning type	1	2
ESS		9.82 (5.23)	
DBAS-16		5.19 (1.76)	
PBAS		5.49 (2.39)	
Psychological characteristics			
HADS(A)		8.69 (3.69)	
HADS(D)		6.82 (4.44)	
MFI		64.16 (15.03)	

Notes. Mean values are presented with standard deviations in parentheses unless otherwise specified. PBAS= Pain-Related Beliefs and Attitudes about Sleep scale. BPI= Brief Pain Inventory. TSK-11= Tampa Scale for Kinesophobia-11. POAM-P= Patterns of Activity Measure-Pain. ISI= Insomnia Severity Index. MEQ= Morningness-Eveningness Questionnaire. ESS= Epworth Sleepiness Scale. DBAS-16= Dysfunctional Beliefs and Attitudes about Sleep. HADS(A)= Hospital Anxiety and Depression Scale (Anxiety). HADS(D)= Hospital Anxiety and Depression Scale (Depression). MFI= Multidimensional Fatigue Inventory.

*Medications for pain, mood and others.

There are a number of important differences in sleep pattern between this sample (i.e., participants with chronic pain) and healthy participants described in Chapter 5. As presented in Table 6.2, compared with participants in Chapter 5, participants with chronic pain, as a whole, achieved an average of 85.38% (SD= 15.94) sleep efficiency, 6.8 hours (SD= 1.91) total sleep time and, 5.66 (SD= 2.13) sleep quality. However, sleep efficiency index from actigraphy showed participants achieved 78.3% (SD= 19.42), which was about 4% lower than sleep efficiency calculated from sleep diary. Participants took an average 34.75 (SD= 46.92) minutes to fall asleep and woke up 3 times during the night (WASO) with mean wake duration of 35.85 minutes (SD= 58.34).

As can be seen from Table 6.2, participants demonstrated higher pain threshold on dominant hand (mean= 27.16 seconds, SD= 41.08) than non-dominant hand (mean= 24.45 seconds, SD= 57.39). However the pain ratings was consistent across both hands with 6.16 (SD= 2.37) for dominant hand and 6.14 (SD= 2.22) for non-dominant hand. An average of both hands showed 25.81 seconds (SD= 45.85) with pain ratings of 6.15 (SD= 2.23).

Generally as a group, overall patterns of participant characteristics and sleep in this study were mild to moderate group compared to chronic pain patients in a daily process study by Tang and colleagues (2012). In this study, participants exhibited higher pain threshold than participants in a study by Desmeules et al. (2003) and Hay et al., (2009).

Table 6.2 *Participants' sleep patterns and pain threshold*

	Variables	*n*= 51
Sleep measure		
Sleep Diary	Average SQ, (NRS 0-10)	5.66 (2.13)
	Average SE, in %	85.38 (15.94)
	Average TST, in hour	6.8 (1.91)
	Average SOL, in minutes	34.75 (46.92)
	Average WASO, times	3
	Average WASO duration, in minutes	35.85 (58.34)
Actigraphy (*n*= 45)	Average A-SE, in %	78.3 (19.42)
Pain threshold		
CPT	Dominant hand, in seconds	27.16 (41.08)
	Dominant hand, pain rating 0-10	6.16 (2.37)
	Non-dominant hand, in seconds	24.45 (57.39)
	Non-dominant hand, pain rating 0-10	6.14 (2.22)
	Average, in seconds	25.81 (45.85)
	Average, pain rating 0-10	6.15 (2.23)

Notes. Mean values are presented with standard deviations in parentheses unless otherwise specified. SQ= Sleep quality. SE= Sleep efficiency. TST= Total sleep time. A-SE= Actigraphy-sleep efficiency. NRS 0-10= Numeric rating scale, from 0= very poor to 10= very good. Pain rating 0-10= from 0 no pain to 10 pain as bad as it could be.

Table 6.3 *Participants' physical activity patterns*

	Variables	*n*= 51
Physical activity measure		
Actigraphy	Average overall level of PA	30826 (10552)
PAMSys	Average running, in seconds	237 (441)
	Average walking, in seconds	33781 (17770)
	Average standing, in seconds	77423 (36444)
	Average sitting, in seconds	146182 (51207)
	Average lying down, in seconds	52115 (45912)

Notes. Mean values are presented with standard deviations in parentheses unless otherwise specified. Level of PA= Level of physical activity.

6.3.2 Multilevel models for exploring the effects of previous night's sleep on next day physical activity

Multilevel models explored the effect of previous night's sleep (SQ, SE, TST, A-SE) on the next day physical activity (level of physical activity, running, walking, standing, sitting, lying down). Table 6.4 presents outcome variables, predictors, fixed coefficient of the predictor(s), the negative log maximum likelihood values, the significance of the predictor(s), and the AIC values. Smaller AIC values suggested better models.

As shown in Table 6.4, TST was not a significant predictor of the overall level of physical activity the next day. SQ, SE and A-SE were found to be significant predictors of the overall level of physical activity the next day. The better the sleep quality and the higher sleep efficiency (i.e., measured by both sleep diary and actigraphy) of the previous night, the greater the overall level of physical activity the next day.

Meanwhile of all 4 predictors, SQ was the only significant predictor of the duration spent sitting (p = 0.012). The better the sleep quality of the previous night, the more time people spent sitting the next day.

Table 6.4 *Results of the Multilevel models for exploring the effects of previous night's sleep on next day physical activity*

Outcome	Predictor	Fixed coefficient	LRT		AIC
			-Log likelihood	*P*- value	
Level of PA	C	2201.9	5906	n.a	11822.1
	C + SQ	1952.5, 44.02	5903	0.038*	11819.9
	C + SE	1562.6, 7.487	5902	0.010*	11817.5
	C + TST	2.185e+03, 4.088e-02	5906	0.910	11824.1
	C	2299.4	5217	n.a	10444.8
	C + A-SE	1882.9, 5.319	5214	0.0204*	10441.5
Running	C	16.931	4036	n.a	8083.3
	C + SQ	9.137, 1.376	4036	0.347	8084.4
	C + SE	-12.341, 0.342	4035	0.086	8082.4
	C + TST	4.431, 0.03	4035	0.237	8083.9
	C	17.622	3595	n.a	7200.3
	C + A-SE	3.657, 0.178	3594	0.292	
					7201.2
Walking	C	2413	6279	n.a	12569.6
	C + SQ	2241.4, 30.28	6279	0.395	12570.9
	C + SE	1903.9, 5.962	6279	0.224	12570.2
	C + TST	2282.2, 0.318	6279	0.603	12571.4
	C	2525.0	5551	n.a	11113.6
	C + A-SE	2049.3, 6.075	5550	0.122	11113.2
Standing	C	5477.4	6680	n.a	13371.0
	C + SQ	5170.2, 54.23	6680	0.382	13372.2
	C + SE	4327.8, 13.464	6679	0.118	13370.5
	C + TST	5177.1, 0.731	6680	0.494	13372.5
	C	5679.3	5901	n.a	11813.7
	C + A-SE	4883.7, 10.159	5900	0.135	11813.4
Sitting	C	10441.6	7087	n.a	14185.1
	C + SQ	8891.2, 273.7	7084	0.012*	14180.8
	C + SE	10211.8, 2.691	7087	0.860	14187.1
	C + TST	1.028e+04, 3.925e-01	7087	0.837	14187.0
	C	10499.0	6240	n.a	12490.3
	C + A-SE	9466.7, 13.18	6239	0.2561	12491.0
Lying down	C	3722.5	7032	n.a	14075.4
	C + SQ	4568.7, -149.4	7031	0.141	14075.2
	C + SE	2886.0, 9.797	7032	0.487	14076.9
	C + TST	2881, 2.051	7032	0.242	14076.0

	C	3959.3	6227	n.a	12465.8
	C + A-SE	3354.9, 7.718	6227	0.5002	12467.4

Notes. LRT= Likelihood ratio test. - Log likelihood= the negative log maximum likelihood. C= Constant. Level of PA= Level of physical activity. SQ= sleep quality. SE= Sleep efficiency. TST= Total sleep time. A-SE= Actigraphy sleep efficiency. n.a= Not applicable. **p* < 0.05. ***p* < 0.01. ****p* < 0.001.

6.3.3 Multilevel models for exploring the effects of daytime physical activity on subsequent sleep

Multilevel models explored the effect of daytime physical activity (overall level of physical activity, running, walking, standing, sitting, lying down) on the subsequent sleep (SQ, SE, TST, A-SE). Table 6.5 presents outcome variables, predictors, fixed coefficient of the predictor(s), the negative log maximum likelihood values, the significance of the predictor(s), and the AIC values.

As can be seen from Table 6.5, the overall level of physical activity and types of physical activity during the day were not significant predictors of the subsequent sleep (SQ, SE, TST, A-SE).

Table 6.5 *Results of the Multilevel models for exploring the effects of daytime physical activity on subsequent sleep*

Outcome	Predictor	Fixed coefficient	LRT		AIC
			-Log likelihood	*P*- value	
SQ	C	5.6634	1278	n.a	2566.0
	C + Level of PA	5.470e+00, 8.838e-05	1277	0.199	2566.4
	C + Running	5.6693934, -0.0003484	1277	0.694	2567.9
	C + Walking	5.750e+00, -3.621e-05	1277	0.368	2567.2
	C + Standing	5.685e+00, -4.029e-06	1278	0.861	2568
	C + Sitting	5.575e+00, 8.555e-06	1277	0.514	2567.6
	C + Lying down	5.643e+00, 5.440e-06	1277	0.693	2567.9
SE	C	85.52	2583	n.a	5176.0
	C + Level of PA	8.482e+01, 3.198e-04	2582	0.513	5177.6
	C + Running	85.454663, 0.004011	2582	0.523	5177.6
	C + Walking	85.841197, -0.0001333	2582	0.641	5177.8
	C + Standing	8.555e+01, -4.993e-06	2583	0.975	5178
	C + Sitting	8.538e+01, 1.340e-05	2583	0.8856	5178.0
	C + Lying down	8.527e+01, 6.646e-05	2582	0.499	5177.5
TST	C	411.95	3975	n.a	7960.5
	C + Level of PA	4.076e+02, 2.006e-03	3975	0.6163	7962.3
	C + Running	410.3478, 0.09483	3973	0.0681	7959.2
	C + Walking	4.103e+02, 6.764e-04	3975	0.773	7962.4
	C + Standing	4.153e+02, -6.182e-04	3975	0.643	7962.3
	C + Sitting	4.073e+02, 4.536e-04	3975	0.553	7962.2
	C + Lying down	4.085e+02, 9.067e-04	3974	0.261	7961.3
A-SE	C	78.219	2476	n.a	4962.4
	C + Level of PA	79.107900, -0.00039	2476	0.590	4964.1
	C + Running	78.12194, 0.005386	2476	0.549	4964.0
	C + Walking	78.877697, -0.000264	2476	0.533	4964.0
	C + Standing	78.80278, -0.000103	2476	0.669	4964.2
	C + Sitting	7.561e+01, 2.492e-04	2474	0.082	4961.4
	C + Lying down	7.786e+01, 8.934e-05	2476	0.530	4964.0

Notes. LRT= Likelihood ratio test. - Log likelihood= the negative log maximum likelihood. C= Constant. Level of PA= Level of physical activity. SQ= sleep quality. SE= Sleep efficiency. TST= Total sleep time. A-SE= Actigraphy sleep efficiency. n.a= Not applicable. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

6.3.4 Multilevel models for exploring the effects of psychological variables upon waking on the subsequent physical activity

Multilevel models explored the effect of psychological variables upon waking (pain, mood, tiredness, fatigue, sleepiness, energy level, body condition, motivation to accomplish tasks, feeling confident to get things done, management of pain right now, and management of pain later) on the subsequent physical activity (level of physical activity, running, walking, standing, sitting, lying down). Table 6.6 presents outcome variables, predictors, fixed coefficient of the predictor(s), the negative log maximum likelihood values, the significance of the predictor(s), and the AIC values.

As presented in Table 6.6, amongst all predictors in this set of analysis, pain (p = 0.0018), mood (p = 0.0149), energy level (p = 0.0130), body condition (p = 0.0155), motivation to accomplish tasks (p = 0.0160), confident to get things done (p = 0.0009), and management of pain right now (p = 0.0247) were significant predictors of the subsequent overall level of physical activity. The results indicate less pain in the morning predicted higher level of subsequent physical activity during the day, whereas with a better mood, a higher energy level, a stronger body condition, a greater motivation to accomplish tasks, a more confident to get things done and a better management of pain right now predicted greater overall level of physical activity.

Further examination of the association between psychological variables upon waking and time spent of different types of physical activity demonstrated that lower level of sleepiness upon waking predicted more time people spent running during the day. Also a more confident to get things done (p = 0.0148) and a better management of pain right now ($p = 0.0161$) significantly predicted greater time spent walking during the day, whereas a higher level of motivation to accomplish tasks ($p = 0.0336$) and a more confident to get things done ($p = 0.0196$) predicted more time people spent standing.

Among all predictors, pain upon waking was found to be a significant predictor of time spent sitting ($p = 0.0126$). The less pain upon waking, the greater time people spent sitting during the day. Among all predictors, pain ($p = 0.0127$), tiredness ($p = 0.0006$) and confident to get things done ($p = 0.0132$) upon waking were significant predictors of time spent lying down, whereby worse pain, more tiredness, and less confident to get things done upon waking predicted more time people spent lying down during the day.

Table 6.6 *Results of the Multilevel models for exploring the effects of psychological variables upon waking on the subsequent physical activity*

Outcome	Predictor	Fixed coefficient	LRT -Log likelihood	LRT *P*- value	AIC
Level of PA	C	2201	5906	n.a	11822.1
	C + Pain	2491, -62.23	5901	0.0018**	11814.5
	C + Mood	1904, 50.87	5903	0.0149*	11818.2
	C + Tiredness	2338, -24.32	5905	0.1806	11822.3
	C + Fatigue	2317, -23.68	5905	0.225	11822.7
	C + Sleepiness	2227, -4.91	5906	0.7727	11824.1
	C + Energy level	1917, 54.29	5903	0.0130*	11818.0
	C + Body condition	1859, 60.82	5903	0.0155*	11818.3
	C + Motivation to accomplish tasks	1940, 43.77	5903	0.0160*	11818.3
	C + Confident to get things done	1798, 64.84	5900	0.0009***	11813.2
	C + Management of pain right now	1850, 52.53	5903	0.0247*	11819.1
	C + Management of pain later	2275, -11.10	5906	0.674	11824.0
Running	C	16.93	4036	n.a	8083.3
	C + Pain	18.33, -0.30	4036	0.8174	8085.2
	C + Mood	5.75, 1.91	4035	0.194	8083.6
	C + Tiredness	28.37, -2.04	4035	0.1062	8082.7
	C + Fatigue	24.67, -1.58	4035	0.2104	8083.7
	C + Sleepiness	30.13, -2.53	4034	0.0298*	8080.6
	C + Energy level	2.87, 2.68	4035	0.07821	8082.2
	C + Body condition	13.94, 0.53	4036	0.769	8085.2
	C + Motivation to accomplish tasks	8.53, 1.40	4036	0.2695	8084.1
	C + Confident to get things done	7.51, 1.51	4036	0.26	8084.0
	C + Management of pain right now	1.21, 2.35	4035	0.1399	8083.1
	C + Management of pain later	4.39, 1.88	4036	0.2751	8084.1
Walking	C	2413	6279	n.a	12569.6
	C + Pain	2679, -57.21	6278	0.0921	12568.8

	C + Mood	2023, 66.73	6278	0.0607	12568.1
	C + Tiredness	2616, -36.22	6279	0.2363	12570.2
	C + Fatigue	2618, -42.18	6279	0.1996	12570.0
	C + Sleepiness	2632, -42.11	6278	0.1405	12569.5
	C + Energy level	2109, 57.90	6278	0.1162	12569.2
	C + Body condition	1986, 75.63	6278	0.07515	12568.5
	C + Motivation to accomplish tasks	2065, 58.24	6278	0.0578	12568.1
	C + Confident to get things done	1909, 80.87	6276	0.0148*	12565.7
	C + Management of pain right now	1779, 94.85	6276	0.0161*	12565.9
	C + Management of pain later	2632, -33.06	6279	0.4573	12571.1
Standing	C	5477	6680	n.a	13371.0
	C + Pain	5862, -82.65	6679	0.1674	13371.1
	C + Mood	4950, 90.34	6679	0.1433	13370.8
	C + Tiredness	5739, -46.79	6680	0.3835	13372.2
	C + Fatigue	5668, -39.28	6680	0.4993	13372.5
	C + Sleepiness	5608, -25.27	6680	0.6149	13372.7
	C + Energy level	5402, 14.25	6680	0.8253	13372.9
	C + Body condition	5114, 64.30	6680	0.3885	13372.2
	C + Motivation to accomplish tasks	4796, 114.16	6678	0.0336*	13368.5
	C + Confident to get things done	4634, 135.5	6677	0.0196*	13367.5
	C + Management of pain right now	4891, 87.70	6679	0.2052	13371.4
	C + Management of pain later	5960, -72.68	6680	0.3509	13372.1
Sitting	C	10441	7087	n.a	14185.1
	C + Pain	11649, -259	7084	0.0126*	14180.9
	C + Mood	10420, 3.542	7087	0.9742	14187.1
	C + Tiredness	10896, -81.13	7087	0.3937	14186.4
	C + Fatigue	10864, -86.67	7087	0.3918	14186.3
	C + Sleepiness	10813, -71.39	7087	0.4208	14186.4
	C + Energy level	10339, 19.57	7087	0.8643	14187.1
	C + Body condition	9426, 180	7086	0.17	14185.2

	C + Motivation to accomplish tasks	9971, 78.83	7087	0.4071	14186.4
	C + Confident to get things done	9672, 123	7086	0.2262	14185.6
	C + Management of pain right now	9648, 118.8	7087	0.3291	14186.1
	C + Management of pain later	9750, 103.9	7087	0.4445	14186.5
Lying down	C	3722	7032	n.a	14075.4
	C + Pain	2609, 238.8	7029	0.0127*	14071.2
	C + Mood	4676, -163.4	7031	0.1063	14074.8
	C + Tiredness	2044, 299.38	7026	0.0006***	14065.7
	C + Fatigue	2885, 171.53	7031	0.0704	14074.1
	C + Sleepiness	3094, 120.57	7031	0.1389	14075.2
	C + Energy level	4159, -83.36	7032	0.4272	14076.8
	C + Body condition	4327, -107.2	7032	0.3765	14076.6
	C + Motivation to accomplish tasks	4609, -148.56	7031	0.0896	14074.5
	C + Confident to get things done	5177, -233.86	7029	0.0132*	14071.3
	C + Management of pain right now	4127, -60.64	7032	0.5932	14077.1
	C + Management of pain later	3024, 105	7032	0.4083	14076.7

Notes. LRT= Likelihood ratio test. - Log likelihood= the negative log maximum likelihood. C= Constant. Level of PA= Level of physical activity. SQ= sleep quality. SE= Sleep efficiency. TST= Total sleep time. A-SE= Actigraphy sleep efficiency. n.a= Not applicable. **p* < 0.05. ***p* < 0.01. ****p* < 0.001.

6.3.5 Multilevel models for exploring the effects of the overall level of physical activity on the subsequent presleep pain and mood

Multilevel models explored the effect of overall level of physical activity on the subsequent pre-sleep pain and mood. Table 6.7 presents outcome variables, predictors, fixed coefficient of the predictor(s), the negative log maximum likelihood values, the significance of the predictor(s), and the AIC values.

As presented in Table 6.7, overall level of physical activity (p = 0.0433) was a significant predictor of pre-sleep mood, with higher level of physical activity predicting better mood at bedtime. Overall level of physical activity did not predict pre-sleep pain in this sample. Figure 6.3 shows results summary of the multilevel models for exploring the relationship from last night's sleep, psychological variables upon waking and subsequent overall level of physical activity, and from daytime overall level of physical activity to nighttime sleep, presleep pain and mood. Figure 6.4 presents results summary of the multilevel models for exploring the relationship from last night's sleep, psychological variables upon waking and subsequent types of physical activity.

Table 6.7 *Results of the Multilevel models for exploring the effects of the overall level of physical activity on the subsequent presleep pain and mood*

			LRT		
Outcome	**Predictor**	**Fixed coefficient**	**-Log likelihood**	***P*- value**	**AIC**
Pain	C	4.959	1320	n.a	2651.5
	C + Level of PA	4.969e+00, -4.213e-06	1320	0.9536	2653.5
Mood	C	5.728	1333	n.a	2677.3
	C + Level of PA	5.399e+00, 1.507e-04	1331	0.04337*	2675.2

Notes. LRT= Likelihood ratio test. - Log likelihood= the negative log maximum likelihood. C= Constant. Level of PA= Level of physical activity. n.a= Not applicable. *p < 0.05. **p < 0.01. ***p < 0.001.

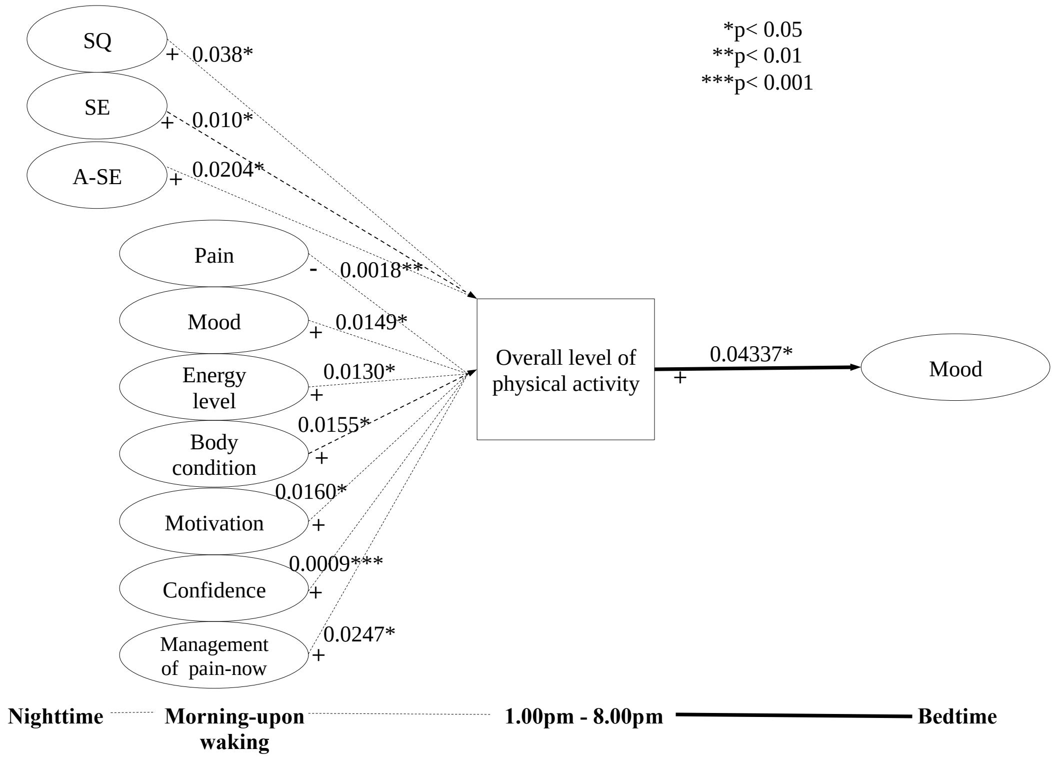

Figure 6.3 Results summary of the multilevel models for exploring the relationship from last night's sleep, psychological variables upon waking and subsequent overall level of physical activity (dotted arrows), and from daytime overall level of physical activity to nighttime sleep, presleep pain and mood (solid arrows).

SQ= Sleep quality. SE= Sleep efficiency. A-SE= Actigrpahy-sleep efficiency. Motivation= motivation to accomplish tasks. Confidence= feeling confidence to get things done. "Nighttime"/ "Morning-upon waking"/ "1.00pm-8.00pm"/ "bedtime"= timeline of sleep, psychological variables and physical activity.

+/- = Indication of the relationship. **p*< 0.05. ***p*< 0.01. ****p*< 0.001.

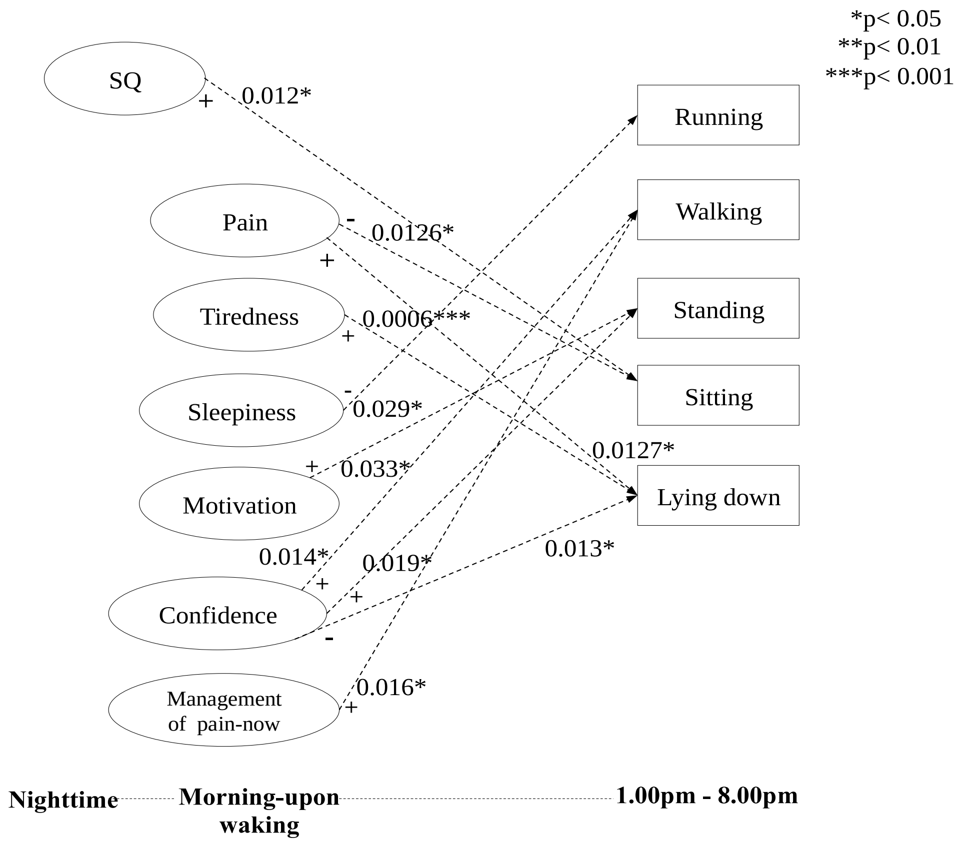

Figure 6.4 Results summary of the multilevel models for exploring the relationship from last night's sleep, psychological variables upon waking and subsequent types of physical activity (dotted arrows). SQ= Sleep quality. Motivation= motivation to accomplish tasks. Confidence= feeling confidence to get things done. "Nighttime"/ "Morning-upon waking"/ "1.00pm-8.00pm"/ "bedtime"= timeline of sleep, psychological variables and physical activity.
+/- = Indication of the relationship. *p< 0.05. **p< 0.01. ***p< 0.001.

6.4 Discussion

The current daily process study extended the previous study presented in Chapter 5 to patients with chronic pain. The findings largely supported the hypothesis that people with chronic pain who have had a better night's sleep were more likely to engage in higher level of physical activity the next day. However, the findings did not support the hypothesis that those who had a higher level of physical activity were more likely to have a better night's sleep on the subsequent night. Hence, the often-assumed reciprocal relationship between sleep and physical activity were not replicated in this study. This is inconsistent with finding from Chapter 5 that found significant association between physical activity and subsequent sleep. Additionally, the current study explored the possible role of the psychological variables upon waking in determining subsequent physical activity. Of these psychological variables, pain, mood, energy level, body condition, motivation to accomplish task, confident to get things done, tiredness, sleepiness, and management of pain right now were found to have significant impact on the sleep-physical activity relationship. Meanwhile, fatigue and management of pain-later were not significant predictors in the sleep-physical activity relationship.

Better sleep quality and higher sleep efficiency but not total sleep time the previous night predicted overall level of physical activity the next day

This study showed that among the four sleep parameters predicting overall level of physical activity the next day, positive associations were found such that higher sleep quality and greater sleep efficiency (derived from both sleep diary and actigraphy) were predictive of higher overall level of physical activity the next day (1.00pm to 8.00pm). These results are consistent with those of previous studies conducted in people without chronic non-malignant pain which demonstrated that higher sleep efficiency, lower wake after sleep onset, less awakenings were associated with greater physical activity the next day (Bernard et al., 2016; Lambiase et al., 2013). In addition, these findings are consistent with results from experimental studies conducted by Schmid et al. (2009) in healthy men. Schmid et al. (2009) demonstrated that acute partial sleep restriction decreases levels and intensity of physical activity.

A *post hoc* analysis with a subsample of patients with chronic pain who scored 15 or higher on the ISI (n= 24) was carried out to examine the extent to which the present finding replicated the finding that sleep quality predicted physical activity the next day from Tang and Sanborn's (2014) study. The finding (i.e., positive association between sleep quality and physical activity the next day) was, consistent with the finding from Tang and Sanborn's study that subjective perception of better sleep quality significantly predicted greater overall level of physical activity the next day (p= .005). Taken together, this has strengthened the view that better sleep has recuperative effects in patients with chronic pain as manifested through increased engagement in daytime physical activity (Horne, 1998; Davies et al., 2008; Spenkelink et al., 2002; Tang, Goodchild, Sanborn et al., 2012).

The current study did not find a significant association between total sleep time and overall level of physical activity the next day. This finding is inconsistent with the finding from Baron et al.'s (2013) study in older women with insomnia demonstrating that shorter total sleep time was associated with next day exercise. They found that participants who were short sleepers exhibited stronger association between shorter total sleep time and shorter exercise the next day. However, participants in Baron et al.'s (2013) study consisted of short sleepers with mean total sleep time was ≤6.5 hours (i.e., 5.5 hours at baseline and 6.4 hours at followed up 16 weeks later). Hence it is possible that the effect of total sleep time might have been inflated because the participants in Baron et al.'s (2013) study were short sleepers. Besides, it could be that total sleep time and physical activity relationship was not detected within-person processes in patients with chronic pain. It seems possible that sleep quality matters more than sleep duration in people with chronic pain.

Waking up with less pain and greater sleep quality were both associated with more sitting during the day.

Findings from this study revealed that patients with chronic pain spent more time sitting after waking up with less pain and/or having had a good night's sleep. Sitting, a specific sedentary behaviour is somewhat difficult for patients with chronic pain specifically patients with chronic back pain. In contrast, pain-free individuals spent most of their time in sitting during waking hours at work or during leisure time (Chau, van der Ploeg, Merom, Chey, & Bauman, 2012; Owen, Healy, Matthews, & Dunstan, 2010; Patel et al., 2010). Of 123216 adults in America, approximately 43% of the participants spent 3-5 hours sitting and 11% spent six hours and more sitting in a day during leisure time (Patel et al., 2010). Spenkelink et al. (2002) demonstrated that patients with chronic low back pain (mean age= 36.6 years, 47.72% of time) spent less time sitting during the day compared to healthy control group (mean age= 29.2 years, 58.59% of time). Patients with chronic back pain were often reported to have low tolerance for extended sitting (Spenkelink et al., 2002; van Deursen et al., 1999). This is possibly because of lack of spinal motion resulting from overexerting of facet-joint occurring after sitting, muscular fatigue and fixed posture (Jensen & Bendix, 1992). The findings may imply that better sleep has a recuperative and restorative function as patients reported less pain upon waking and thus leading them to spend more time sitting.

No significant temporal association from daytime physical activity to subsequent sleep

Contrary to the hypothesis, none of the daytime physical activity variables predicted subsequent sleep. Although these findings differ from some published studies (e.g., Lang et al., 2016; Reid et al., 2010), they are consistent with those of Lambiase et al.'s (2013) study in older women and Youngstedt et al.'s (2003) study in normal sleepers. A possible explanation for the non-significant association of daytime physical activity and the subsequent sleep is that the timeframe of physical activity included in the analysis was from 1.00pm to 8.00pm. This timeframe was chosen because taking into consideration each participant's bedtime and wake up time and it has both advantages and limitations. The advantage of conducting the analysis of physical activity from 1.00pm to 8.00pm was to demonstrate a clear and precise chronological order of the predictor and predicted variable (e.g., daytime physical activity and nighttime sleep did not overlap). However, the limitation was this would exclude those who engaged in physical activity in the morning or those who were physically active in the late evening as people with chronic pain can exhibit large variations in timing and frequency of physical activity (Hasenbring et al., 2006; Verbunt et al., 2012). Besides, it seems possible that this non-significant finding maybe due to the types and intensity/level of physical activity. Previous studies that showed significant association between physical activity and sleep when the physical activity was planned, structured, and regular (e.g., Hertescu et al., 2015; Reid et al, 2010). For example, Hertescu et al. (2015) asked participants to engage in at least 150 minutes of moderate-intensity physical activity in a week. Participants were asked to do “brisk walking” for at least 30 minutes per day on at least 5 days in a week. Similarly, Reid et al. (2010) asked participants to perform aerobic activities comprising walking, stationary bicycle or treadmill for four times per week (30-40 minutes each session). Moreover, Kline et al. (2013) found that among types of physical activity namely recreational physical activity (e.g., sport/exercise), lifestyle-related activity (e.g., walking to work) and household-related activity (e.g., housework, childcare), only a high level of recreational physical activity was linked to better sleep among women (n= 339, mean age= 52.2 years). Specifically, Kline et al. (2013) reported that higher recreational physical activity was associated with better sleep quality (derived from sleep diary, $p< .01$), greater sleep efficiency (derived from sleep diary, $p< .05$), and greater sleep depth as measured by polysomnography (i.e., higher NREM delta power, $p= .04$; lower NREM beta power, $p< .05$). In light of this, it seems possible that the spontaneous day-to-day physical activity of people with chronic pain in the present study might not be regular and structured. Possibly, there were variations in daily physical activity resulting in the absence of consistent normal daily routines of physical activity and hence the effect could not be seen.

Better mood upon waking predicted higher overall level of physical activity, which in turn led to better presleep mood

Another key observation was that the findings demonstrated a reciprocal link between mood and physical activity. Participants with chronic pain who reported experiencing better mood upon waking spontaneously engaged in more daytime physical activity, which in turn was followed by better mood during the presleep period. The finding (better mood predicted higher overall level of physical activity) differs from the findings of previous studies (Vendrig & Lousberg, 1997; Tang & Sanborn, 2014), which showed that mood was not significantly linked to physical activity in chronic pain patients. The discrepancy of the findings might be attributed to the assessment of mood and physical activity. In Tang and Sanborn's (2014) study, mood was assessed in the morning upon waking and physical activity was assessed from noon to 11.00pm. Meanwhile in Vendrig and Lousberg's (1997) study, mood and physical activity was assessed 8 times a day in a random time schedule. Mood regulation has been associated with sleep disturbance and chronic pain (Morin et al., 1998; Nicassio & Wallston, 1992; O'Brien et al., 2010) in which, sleep disturbance interacts with mood to effect physical functioning and regulation of diurnal patterns (Smith et al., 2009; O'Brien et al., 2010).

This dysregulation of diurnal patterns decreases physical and social activities during the day or increases time in bed.

Finding of the present study also demonstrated that higher overall level of physical activity during the day significantly predict better mood during presleep period. This finding is consistent with the findings of randomised-controlled trials in people with insomnia (Hertescu et al., 2015; Reid et al., 2010). In a RCT, Hertescu et al. (2015) recruited 41 inactive adults with insomnia (≥40 years old, mean age= 59.8 years) to be allocated to either the intervention group or control group. The intervention group was asked to perform ≥150 minutes of moderate- to vigorous-intensity physical activity per week (i.e., walking for at least 30 minutes per day, which is spread on at least 5 days in a week), for 6 months. Whereas, the control group was asked to maintain their baseline physical activity level and just continue their daily lifestyle as usual, for 6 months. Hertescu and colleagues (2015) found that engagement in minimum level of physical activity (i.e., 150 minutes of moderate-intensity physical activity in a week) significantly decreased depression and anxiety symptoms among inactive individuals with insomnia. The improvement was found to be independent of average daily light exposure and participants' health and social status. Reid et al. (2010) found similar findings in a RCT assessing the effectiveness of 16 weeks of moderate aerobic physical activity among sedentary adults with chronic insomnia (n= 17, mean age= 61.6 years). Participants were randomly assigned to either an aerobic physical activity group or non-physical activity group. Participants in the physical activity group were asked to exercise for either two 20 minutes session or one 30-40 minutes session for 4 times per week. Findings showed that physical activity group demonstrated reductions in depressive symptoms (p= .044) at follow-up 16 weeks later. Notably, the findings from both studies (i.e., Hertescu et al., 2015; Reid et al., 2010) showed that physical activity significantly reduced depressive symptoms among inactive/ sedentary adults with insomnia. Furthermore, exercise intensity and duration have been reported to have an acute effect on mood state (Hoffman & Hoffman, 2007; Yeung, 1996). There is a minimum threshold for intensity and duration of physical activity to elicit analgesia effect. Using a repeated-measures design, Hoffman et al. (2004) examined how exercise-induced analgesia was affected by the duration and intensity of aerobic exercise in 12 healthy participants (mean age= 32 years). Participants were asked to come to the laboratory 5 times at approximately the same time of the day. Participants' pain ratings were assessed before and after treadmill exercise (at 5 and 30 minutes). Pain was assessed using a 2-minute pressure pain stimulus to the non-dominant index finger. Participants were asked to perform treadmill exercise for 10 and 30 minutes. Findings demonstrated that a threshold of 10 minutes and intensity (at least 50% oxygen uptake) were required to elicit exercise-analgesia. However, this finding needs to be confirmed in people with chronic pain.

The significant roles of pain, mood, energy level, body condition, motivation to accomplish task, confident to get things done, tiredness, sleepiness, and management of pain (right now) upon waking in determining subsequent daytime physical activity

The roles of pain, mood, tiredness, fatigue, sleepiness, energy level, body condition, motivation to accomplish tasks, confidence to get things done, management of pain right now, and management of pain later in predicting physical activity were explored alongside sleep. Of these 11 psychological variables, pain, mood, energy level, body condition, motivation to accomplish task, confidence to get things done, tiredness, sleepiness, and management of pain (right now) were found to be significant predictors of subsequent physical activity. Fatigue and management of pain-later did not predict subsequent physical activity. Such that mornings of less pain, better mood, higher energy levels, stronger body condition, greater motivation to accomplish tasks, more confident to get things done and better management of pain right now were followed by days of higher overall level of physical activity.

Potentially, these psychological variables indicate that non-specific feelings upon waking may be related with a restorative sleep. In fact, non-restorative sleep is one of the main complaints in people with fibromyalgia (Moldofsky et al., 1975; Theadom et al., 2007; Wolfe & Häuser, 2011). Using a daily process study design, Tang, Goodchild, Sanborn et al. (2012) investigated the temporal association between sleep quality of the previous night and pain upon waking in 119 patients with chronic pain. The findings revealed that higher sleep quality and greater sleep efficiency predicted less pain the subsequent morning. This reflects the notion that good sleep quality may improve pain and other relevant psychological symptoms such as depressive symptoms (Davies et al., 2008; Nicassio et al., 2002). Davies et al. (2008) conducted a population-based prospective study in people with chronic widespread pain. Of 1061 participants reported chronic widespread pain at baseline, 679 participants completed the questionnaires at follow up 15 months later. The restorative sleep was assessed using an item in the Estimation of Sleep Problem Scale *(During the past month did you wake up after our normal amount sleep feeling tired and worn out?*). Of 679 participants, 44% of the participants no longer meet the criteria for chronic widespread pain. The restorative sleep remained the only factor that was independently related with symptoms resolution even after adjusting for psychosocial factors, age and gender (OR= 2.0, 95% CI, 1.0-3.8). Davies et al.'s (2008) results suggest that restorative sleep was associated with the resolution of chronic widespread pain and return to the musculoskeletal health.

Taken together, these findings highlight that various psychological factors assessed upon waking in the morning might influence daytime physical activity in people with chronic pain. The significant roles of these psychological variables are consistent with the FAM (see Figure 2.7, Chapter 2) for example when a participant could manage the pain and is confidence to get things done, this would result in reducing excessive pain-related fear. Therefore, it is important to clinicians/ physicians to take into consideration these psychological correlates when designing treatment plan or intervention programme to promote physical activity (Glombiewski et al., 2010; Volders, Meulders, De Peuter, & Vlaeyen, 2015).

Strengths, limitations and implications

The methodological strength of the present daily process study is its time-lagged data. Despite that the design cannot establish the evidence for a causal relationship, this time-lagged data establishes a temporal precedence of the sequential relationship between sleep and physical activity in the participants' natural sleeping and living environment. In addition, it increases the ecological validity of the findings. The repeated measurement of sleep, physical activity and psychological variables taken at specific times might detect changes that occur in these processes over 14 days of the assessment period. The daily process study allowed the analysis to look at the relationship between sleep, physical activity and psychological variables across nights and days within a participant rather than the relationship between variables across participants.

Limitations of this daily process study need to be acknowledged and the findings must be interpreted in the light of these limitations. First, some studies have shown that individuals' engagement in physical activity might vary based on their circadian preferences (e.g., Kline et al., 2007; Schaal, Peter, & Randler, 2010; Thun et al., 2012; Vitale, Calogiuri, & Weydahl, 2013). Vitale et al. (2013) conducted a pilot study to examine the influence of individual chronotype and exercise in healthy adults (n= 12, mean age= 23 years). They found that participants who were evening-types appeared at a disadvantage when carrying out the walking task in the morning (i.e., lower walking speed with higher rating of perceived exertion). In contrast, participants who were Morning-type exhibited lower rating of perceived exertion when carrying out the walking task in the morning. Further studies, which take circadian rhythm into account, will need to be undertaken. Second, the present study recruited heterogeneous patients with chronic pain to maximise the clinical relevance of the study and comprised nearly 60% of individuals who are working full- and part-time, and studying full-time.

Moreover, the mean age of participants in the present study were relatively young compared to participants in the previous studies (e.g., Tang & Sanborn, 2014; Bernard et al., 2016). Therefore findings of the present study maybe more relevant to the individuals with similar demographic characteristics. Third, energy expenditure (based on overall level of physical activity/ different types of physical activity) was not assessed in the present study. Changes in occupational activities (such as from being employed to unemployed) could affect daily energy expenditure in people with musculoskeletal pain (Verbunt, Huijnen, & Köke, 2009). Oudegeest-Sander et al. (2013) reported that energy expenditure was significantly associated with sleep efficiency in healthy young adults (mean age= 27 years, r= .627, p= .029) but this relationship was not found in healthy older adults (mean age= 69 years, r= -.158, p= .49). They suggest that energy expenditure was altered in older adults but it is not known if energy expenditure would be altered in people with chronic pain. In future investigations, it might be possible to use a physical activity-monitor that is equipped with energy expenditure estimation.

The present findings have some potential implications. If sleep is a key determinant of next day physical activity in people with chronic pain, it may be worth to intervene and treat sleep problems and other comorbidities (e.g., depression). Possibly, applying hybrid treatment that improves sleep and other sleep comorbidities could be a treatment option. Tang, Goodchild and Salkovskis (2012) randomised individuals with chronic pain comorbid insomnia to receive 4 weekly 2 hours sessions of hybrid treatment (hybrid treatment) or to keep a pain and sleep diary for 4 weeks (monitoring group). The hybrid treatment consists of eight treatment components comprising sleep psychoeducation, stimulus control therapy, sleep restriction therapy, cognitive therapy, individual formulation, goal setting and behavioural activation, reducing pain catastrophising and safety-seeking behaviour, and reversing mental defeat. Participants in the hybrid treatment showed greater improvement in sleep compared to the monitoring group. Participants in the hybrid group also demonstrated greater reduction in pain interference, fatigue and depression than participants in the monitoring group. In addition, applying intervention that aim to improve and alter subjective perception of sleep quality upon waking in the morning could also be an effective way to increase daytime physical activity levels. Besides, participants need to be trained to regulate their daytime physical activity according to their pace. It is because if participants increase physical activity levels after a night of good sleep, they could potentially engage in excessive physical activity which in turn will amplify their pain intensity (Scascighini & Sprott, 2008). Tang, Goodchild, Sanborn et al. (2012) found that sleep efficiency (estimated from actigraphy) predicted less pain upon waking and more pain during the second half of the day in patients with chronic pain (*n*= 119, mean age= 46 years). Tang et al. (2012) argued that patients with chronic pain might undertake more activity on days whey they had better sleep quality or less pain. Consequently, overactivity is likely to occur with increased pain during the second half of the day. Furthermore, some patients with chronic pain would persist with the activity despite pain (Hasenbring & Verbunt, 2010). This has raised a philosophical question whether an increase level of physical activity is necessarily good for patients with chronic pain. It might increase pain if they have done too much during the day or it might cause acute night pain as a result of stiffness. Therefore, it is important for the patients with chronic pain to know their limit when undertake physical activity and not go beyond what they could physically manage.

Conclusion

In conclusion, despite the limitations discussed previously, this daily process study has demonstrated the predictive value of sleep quality, sleep efficiency and a few psychological variables specifically morning pain and mood in predicting daytime physical activity the next day. However, the findings did not find evidence of the often-assumed bidirectional relationship between sleep and physical activity at the within-person level. The findings support previous daily process study by Tang and Sanborn (2014) which demonstrated patients with chronic pain who had a better night's sleep spontaneously engaged in more daytime physical activity the subsequent day. Given that, this may have implications for understanding the unobserved homeostatic relationship between nighttime sleep and physical activity the next day in people with chronic pain. The present findings further highlight the potential benefits of designing future intervention studies to apply hybrid treatment targeting both sleep disturbance and chronic pain particularly in people with chronic pain characterised by sleep disturbance. Potentially, improvements in sleep maybe a key determinant to increase physical activity the next day in physically inactive patients with chronic pain.

Chapter 7

General Discussion

7.1 Summary of the key findings

This thesis utilised a multi-methodological approach to investigate the definition of sleep quality and to examine the association between sleep and physical activity in people with chronic pain and in healthy individuals. People with chronic pain often complain that their sleep is of poor quality. Previously, studies have shown that people with and without insomnia define sleep quality using nighttime sleep parameters, nonspecific feelings upon waking and tiredness during the day. However, it remains unclear how people with chronic pain define their sleep quality and to what extent their judgment differ by the presence of pain (i.e., widespread musculoskeletal pain, localised pain, no pain). Apart from using a qualitative approach to explore the definition of sleep quality, the present thesis also examined the relative importance of 17 possible sleep quality parameters using a quantitative approach. The study also investigated the effects of parameter timing, existing sleep status and question type. Having discussed the definition of sleep quality from qualitative (see Chapter 3) and experimental (see Chapter 4) approaches, the second part of the thesis addresses the temporal and bidirectional association between sleep and physical activity using two daily process studies (see Chapter 5 and 6). Key findings of all studies are presented in Table 7.1.

Table 7.1 *Overview of the key findings*

Chapter	Key findings
3	Thematic analysis of interviews with six participants with fibromyalgia, five participants with back pain, and six pain-free individuals revealed that sleep quality judgements were typically made based on four main considerations: 1) Memories of nighttime sleep disruptions. 2) Feelings on waking and cognitive functioning during the day. 3) Ability to engage in daytime physical and social activity. 4) Changes in physical symptoms and pain intensity. The findings demonstrated that the judgements of sleep quality were similar across people with and without chronic pain. However, introspection of pain intensity only applied to people with chronic pain. People with chronic pain also explicitly described their poor sleep and pain as a vicious cycle.
4	The experimental study conceptualised sleep quality judgement as a decision-making process and investigated the relative importance of 17 possible sleep quality parameters in 50 good sleepers and 50 poor sleepers. Using a choice-based conjoint analysis, participants were asked to choose between two concrete descriptions of sleep/wake scenarios to answer questions “Which describes a better (or worse) night of sleep?”. Each scenario consisted of 17 possible sleep quality parameters that were combined together to generate a first-person account of sleep experience. Logistic regression models were fit to the participants’ choice data. The findings revealed that: 1) 11 of the 17 sleep quality parameters had a significant impact on the participants’ choices. The parameters were *physiological arousal*, *sleep onset latency*, *wake after sleep onset*, *total sleep time*, *feeling refreshed*, *motivated to get up*, *alertness*, *thinking*, *mood*, *sociability*, and *physical activity*. 2) *Total sleep time, feeling refreshed (upon waking)*, and *mood (day after)* were the top three determinants of sleep quality. 3) The judgements of sleep quality were most influenced by parameters that occur *during sleep*, followed by feelings and activities *upon waking* and the *day after.* 4) There was a significant interaction between *wake after sleep onset* and *feeling refreshed (upon waking)*. *Wake after sleep onset* and *feeling refreshed (upon waking)* might not functionally synonymous but interacting parameters of sleep quality. 5) There was a significant interaction between *feeling refreshed (upon waking)* and question type (better or worse night of sleep). *Feeling refreshed* was more important to the participants when judging a good night’s sleep than when judging a poor night’s sleep.

	6) Types of sleeper (good or poor sleepers) did not significantly influence the judgements of sleep quality. Good and poor sleepers have similar judgements of sleep quality.
5	The daily process study examined the within-temporal association between different indices of sleep (sleep quality, sleep efficiency, total sleep time) and daytime physical activity (overall level of physical activity, running, walking, standing, sitting, lying down) in 118 healthy young adults. Using self-reported measures of sleep and physical activity, participants were trained to monitor their sleep and physical activity in their natural living and sleeping environment for 7 days. Multilevel models were run: (1) to examine the effect of sleep on physical activity the following day, (2) to examine the effect of physical activity on the subsequent sleep. Multilevel models for exploring the effect of sleep on physical activity the following day revealed that: 1) Lower sleep quality predicted more time spent lying down the next day. 2) Shorter total sleep time predicted more time spent walking the next day. Multilevel models for exploring the effect of physical activity on the subsequent sleep revealed that: 1) Less time spent on overall level of physical activity during the day predicted longer total sleep time the subsequent night. 2) Less time spent on running predicted longer total sleep time the subsequent night. 3) Greater time spent lying down predicted longer total sleep time the subsequent night.
6	This daily process study adapted and extended the methods established in Chapter 5 to examine the within-person temporal association between sleep and physical activity in 51 patients with chronic pain. Using both self-reported and objective measures of sleep and physical activity, participants were trained to monitor their sleep and physical activity in their natural living and sleeping environment for 14 days. Multilevel models were run: (1) to examine the effect of sleep on physical activity the following day, (2) to examine the effect of physical activity on the subsequent sleep, (3) to examine the effect of pain and psychological variables upon waking in the morning on the subsequent physical activity, (4) to examine the effect of overall level of physical activity on the subsequent pre-sleep pain and mood. Multilevel models for exploring the effect of sleep on overall level of physical activity the following day revealed that: 1) Better sleep quality predicted higher overall level of physical activity the next day. 2) Higher sleep efficiency predicted greater overall level of physical activity the next day.

3) Higher actigraphy-sleep efficiency predicted greater overall level of physical activity the next day.

Multilevel models for exploring the effect of sleep on different types of physical activity the following day revealed that:

1) Better sleep quality predicted more sitting the next day.

Multilevel models for exploring the effect of physical activity on the subsequent sleep revealed that:

1) Overall level of physical activity and different types of physical activity during the day were not significant predictors of subsequent sleep.

Multilevel models for exploring the effect of psychological variables upon waking in the morning on the subsequent physical activity (overall level of physical activity) revealed that:

1) Less pain upon waking predicted higher overall level of physical activity
2) Better mood predicted higher overall level of physical activity
3) Higher energy levels, stronger body condition, greater motivation to accomplish tasks, more confident to get things done and better pain management right now predicted higher overall level of physical activity.

Multilevel models for exploring the effect of pain and psychological variables upon waking in the morning on the subsequent physical activity (different types of physical activity) revealed that:

1) Less sleepiness upon waking predicted more running during the day.
2) More confident to get things done and better management of pain right now predicted more walking during the day.
3) Greater motivation to accomplish tasks and more confidence to get things done predicted more standing during the day.
4) Less pain upon waking predicted more sitting during the day.
5) More pain and greater tiredness predicted more lying down during the day.

Multilevel models for exploring the effect of overall level of physical activity on the subsequent pre-sleep pain and mood revealed that:

1) Greater overall level of physical activity during the day predicted better presleep mood. However overall level of physical activity was not a significant predictor of presleep pain.

7.2 Discussion of overall findings

From the qualitative (Chapter 3) and experimental (Chapter 4) studies discussed in this thesis, sleep quality appears to involve retrospective decision-making process influenced by both nighttime and daytime parameters. There was consistency in the findings that emerged across the two studies. This combination of findings reflects previous results from Harvey et al.'s (2008) study suggesting that people with and without insomnia used multiple criteria to define their sleep quality. The judgement of sleep quality involves retrospective decision-making process using information that is accessible to the individuals. This suggests that sleep quality judgement is a fluid concept, which is not fixed, that can be changed or renewed as people might change their judgement depending on their experiences during the day. Both studies also indicated that sleep quality judgement were similar across different group of people. The study in Chapter 3 included three diagnostic groups (i.e., participants with localised pain, musculoskeletal pain and no pain) as this allowed to compare and contrast sleep quality judgements across diagnostic groups. This approach has helped to enrich the data and overcome methodological limitations concerning studies with one homogenous group of participants such as Kleinman et al.'s (2013) study, which recruited participants with insomnia only. Meanwhile, the study in Chapter 4 recruited both good and poor sleepers. The experimental method complements the qualitative method by examining the relative importance of sleep quality parameters. More importantly, these findings have shown for the first time the top individual sleep quality parameters that influence the judgement of sleep quality. Whilst multiple parameters of sleep quality have already been identified in the previous studies such as the parameters associated with sleep quality ratings (e.g., Yi et al., 2006; Westerlund at al., 2014; Akerstedt et al., 1994; Kleinman et al., 2013; Harvey et al., 2008; Akerstedt et al., 1997; Carey et al., 2005; Webb et al., 1976), none of the studies have focused on examining the relative importance of those parameters and how they may interact in influencing people's judgement of sleep quality. Taken together, a combination of qualitative and experimental approaches has contributed to improve understanding of the specific parameters that could sway people's judgements of their sleep quality.

Findings from daily process studies presented in Chapters 5 and 6 demonstrated significant temporal within-person associations between different indices of sleep and physical activity the next day. However, there are inconsistent findings between the daily process study in Chapter 5 and daily process study in Chapter 6. Sleep quality and total sleep time predicted specific types of physical activity but did not predict overall level of physical activity in people without chronic pain. Sleep efficiency was not a significant predictor of overall level of physical activity and different types of physical activity the next day in people without chronic pain (Chapter 5). Meanwhile sleep quality, sleep efficiency and actigraphy-sleep efficiency predicted overall level of physical activity the next day in people with chronic pain. Total sleep time was not a significant predictor of overall level of physical activity and different types of physical activity the next day people with chronic pain (Chapter 6). This suggests that at the within-person level, different sleep indices have different roles in different groups of people. For example, perception of better sleep quality may be more important than longer total sleep time in people with chronic pain as they often complain of unrefreshing sleep and poor sleep quality (Theadom et al., 2007; Wolfe & Hauser, 2011). People with chronic pain who slept well may feel more refreshed and be more likely to engage in physical activity the following day. They may pay less attention to the amount of sleep as their sleep tend to be fragmented and vary a great deal from one night to the next (Theadom & Cropley, 2010). In contrast to healthy pain-free who are generally good sleepers, their sleep maybe more regular every night, hence getting a certain amount of sleep is necessary and important to them. In addition, the inconsistent findings between daily process studies in Chapters 5 and 6 could be attributed to the different measures of physical activity. The study in Chapter 5 used self-reported measure of physical activity, while the study in Chapter 6 used objective measure to track physical activity. As discussed in Chapter 2, both self-reported measure and objective assessment of physical activity have advantages and limitations. Verbunt et al. (2012) argued that people's psychological state (e.g., mood) could influence people's perception when completing the self-report diary. Therefore, self-report measures are only moderately associated with objective assessment (Verbunt et al., 2005). Nevertheless, both are widely used and accepted methods to measure physical activity. To enhance the comparability of findings between people with and without chronic pain, futures studies would need to use the same measures of physical activity in the same study. The daily process study in Chapter 6 showed that pain and some psychological variables (i.e., mood, energy level, body condition, motivation to accomplish task, confidence to get things done, tiredness, sleepiness and management of pain-right now) were independently found to be significant predictors of subsequent physical activity. These findings establish associations but have a lack of information on the relative contributions of the predictors. Future studies may want to examine the relative contributions more closely.

The findings across studies (Chapters 3, 4, 5 and 6) converge to suggest that sleep quality judgement may influence subsequent physical activity in people with chronic pain. Therefore, it may be worthwhile to target sleep quality judgement for intervention. It is important to educate people about the judgement of sleep quality specifically people with chronic pain as they might hold unhelpful belief about the interaction between sleep and their pain. Examples of unhelpful beliefs are "*the pain is always there when I try to have a good night's sleep*", "*I know I can't sleep through the night because the pain will wake me up*", "*Unless I get rid of the pain, I won't sleep well*" (Afolalu et al., 2016). These maladaptive beliefs could further worsen sleep disturbance in people with chronic pain and consequently reduce daytime physical activity (e.g., Harvey, 2002; Lund & Broman, 2000). Improvements in sleep quality will not only increase engagement in physical activity, but also overall quality of life.

7.3 Overall limitations of the research

A number of crucial limitations of this thesis need to be considered. First, the generalisability of the quantitative-choice making study (Chapter 4) is limited in terms of participants' demographic characteristics. Participants were not patients with insomnia who were actively seeking medical or nonpharmacological treatment. Hence, the findings may not be applicable to the clinical population with severe insomnia symptoms or patients with chronic pain comorbid sleep impairments. Besides, the participants were primarily drawn from university community. Possibly, the results are more applicable to the high achieving young adults and maybe less applicable to other less educated young adults or less privileged populations. Using data from the British Psychiatric Morbidity Survey 2000, Arber, Bote and Meadows (2009) examined the association between socio-economic circumstances and sleep disturbance in 8578 participants aged 16 to 74 years. Arber et al. (2009) reported that those with low educational qualifications and those unemployed demonstrated significantly greater sleep problems compared to those with high education and those employed, even after adjusting for other potential mediators such as smoking, worrying, health and depression. Although the findings from the present quantitative-choice making study are promising (Chapter 4), future research should consider replicating the findings in a more varieties of homogenous samples (e.g., patients living with chronic medical/psychiatric conditions, patients with severe insomnia symptoms, unemployed, low education or other various demographic background).

Second, chronic pain patients in the present studies (Chapters 3 and 6) were advised to keep to their medical regimen and to take their medications as commonly prescribed. This has given both advantage and limitation to the study. Apart from ethical reasons, keeping to the patients' medical routine could establish a more naturalistic observation of sleep and pain experience within the patients of the present studies. However, a limitation is that some of the medications used by the participants such as analgesics, opiods, antidepressants and NSAIDs are known to have an effect on sleep (Onen, Onen, Courpron, & Dubray, 2005; see Table 6.1 for a list of medication used by the participants). Onen et al. (2005) reported that sleep disturbance in patients with chronic pain (e.g., increased wakefulness and stage 1 NREM sleep) may be associated with the pain, analgesic and sedative medications prescribed. With a small sample size of the patients with chronic pain (Chapter 6), it is not appropriate to classify them into a group of patients who do not experience sleep disturbance or who use/ do not use the medications.

Methodologically, the daily process study (in Chapters 5 and 6) has advantage of providing data from the within-person level over time, which overcomes the huge between day variations specifically in people with chronic pain. Besides, the time-specific nature of the data reflected the lagged design, which helps describes temporal precedence of the predictor and the predicted variable. However, the daily process study is limited by the absence of a causal relationship between variables. Therefore, the findings did not imply causation between sleep and physical activity.

7.4 Implications and future directions

Overall, findings from the present research have important research and clinical implications for understanding and developing intervention to improve sleep and physical activity specifically in people with chronic pain. First, the novel methodological approach of quantitative choice-making study (Chapter 4) has paved ways for eliciting information and unpacking a subjective, less consistently defined concept such as sleep quality. This approach could be applied to different population and extended to understanding other concept such as fatigue and quality of life. For instance, quality of life is a broad concept that encompasses multidimensional factors (e.g., psychological, physical health, social relationship, employment). Different patients might have different understanding of what quality of life means to them. The use of this approach could present patients with potential features of quality of life and ask them what they consider features of quality of life. This could help clinicians to identify potential features of quality of life that may differ between patients.

Second, recent advances in wearable technology have opened up potential methods for collecting big data of sleep and physical activity in the observational studies. For example the Fitbit, a relatively affordable and commercially available wearable device that is equipped with sleep, physical activity and heart rate tracker could be used in future observational studies. Although the data and algorithm of this new technology may need further validation studies (Diaz et al., 2016; Paul et al., 2015), using such technology could provide accessibility to a large patient-generated data.

Third, the findings also have implications for subsequent intervention and treatment planning. Public health awareness should broaden the focus to addressing perception of sleep quality and the impact of poor sleep on daytime functioning. For patients with chronic pain, it is potentially feasible to address sleep problem despite chronic pain to improve sleep, physical inactivity and the overall quality of life. Applying hybrid treatment could open up a new avenue to treat sleep specifically in people with chronic pain comorbid with other medical conditions such as mood disturbance. The hybrid treatment has been found to improve not only sleep, but also mood, fatigue and other pain-related outcomes (Tang et al., 2012).

7.5 Overall conclusion

The work presented in this thesis provides mixed methods examining sleep quality judgement and the association between sleep and physical activity. Through qualitative and novel choice-making studies of the judgement of sleep quality, the findings indicated that sleep quality judgements were retrospectively determined by both nighttime parameters and daytime processes. Meanwhile, through daily process studies conducted in healthy and patients with chronic pain, the findings indicate the significant temporal within-person association between sleep and physical activity. Specifically, nights of higher sleep quality were followed by days of higher physical activity levels. In sum, the main contributions of the thesis across studies, is that sleep quality is dependent on daytime processes and subsequently affects daytime functioning (e.g., physical activity, mood) in chronic pain patients. Hence, the key focus of future investigations and interventions should consider the possibility of broadening the treatment focus to addressing chronic pain patient’s perception of sleep quality and the impact of poor sleep on daytime processes, for improving sleep quality, engagement in physical activity and the overall quality of life.

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Appendices

Appendix 1: Study 1 - Participant information sheet

THE UNIVERSITY OF WARWICK

PARTICIPANT INFORMATION SHEET

Exploring the definitions of sleep quality: A qualitative study with people with fibromyalgia, back pain and those without chronic pain.

My name is Fatanah Ramlee. I am a PhD student studying Psychology at The University of Warwick. Currently I am running a study exploring the definitions of sleep quality among people with and without chronic pain. I would like to invite you to take part in the study.

Aims of the study
The study aims to gain an insight into the criteria people use to judge their sleep quality. We are interested in hearing your stories and would like to ask you how you make your judgement about your sleep quality, at different times of a day.

What do you have to do if you agree to take part?
If you agree to take part in the study, you will be asked to:

- complete a set of questionnaires about yourself, health conditions, pain, sleep, moods, and daily physical activities. The questionnaires will take approximately 20-30 minutes to complete. You can fill out the questionnaire one or two days before the interview at your convenience and at your own pace;
- attend an interview at the University of Warwick in which I will ask you to talk about your sleep and the way you judge your sleep quality. With your permission, the interview will be audio-taped. The interview is exploratory in nature and will be conducted in a relaxed and informal manner. It will be approximately 30-45 minutes long and can be arranged to a date that best suits your schedule.

Participant's Rights
Your participation in this study is totally voluntary. If at any point of the study you feel uncomfortable and you want to withdraw from the study, you may do so without giving a reason and without jeopardizing your opportunity to take part in future studies.

Confidentiality
Information will be kept strictly confidential. All participants will be given a unique ID number. Questionnaire data and interview transcripts will be anonymised and only members of the research team will have access to the anonymised data. We will handle your personal information in accordance with the Data Protection Act 1998. Your identity will not be disclosed in the report of the findings.

Reimbursement
We will reimburse your travel expenses up to £20 if you could provide us the receipt.

Approval
The research protocol has been reviewed and approved by the Ethics Committee of the Department of Psychology, The University of Warwick, Coventry CV4 7AL, UK.

Should you require further information, please do not hesitate to contact me on +44(0) 24765 73469 or via email F.Ramlee@warwick.ac.uk. For independent advice, you may contact my supervisor Dr. Nicole K. Y. Tang on +44(0) 2476150556 or at n.tang@warwick.ac.uk.

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Appendix 2: Study 1 - Participant screening form

THE UNIVERSITY OF WARWICK

PARTICIPANT SCREENING FORM

Participant's name : ______________________________

Participant's telephone : ____________________ Age: ______

Participant's address : ______________________________

____

Postcode : ________________ Gender: _________

Participant's email : ______________________________

Please tick ( ) the following information that is applicable to your current situation:

	Aged between 18 and 65
	English speaking
	Nonmalignant pain
	have been experiencing pain for 6 months and longer
	have problems sleeping
	have no problems sleeping
	have no disabilities that prevent from participation such as visual or hearing impairment, dementia, learning disability, and terminal illness
	have no severe psychopathology or psychiatric illnesses (e.g.: substance abuse, bipolar disorder, and psychosis)
	have no organic sleep disorders (e.g.: narcolepsy, sleep apnea, and rest leg syndrome)
	Pregnant

ISI

Please answer by ticking ( ) the following questions with reference to your sleep in the <u>last week</u>.

1. Did you have any difficulty sleeping in the last month?
   Yes ( ) No ( )

*If the answer is '**Yes' to question 1**, "*Are you taking any medication(s) for your sleep*?"
Yes ( ); Please specify the sleep medication name: ______________________
Dosage/ frequency: ______________________
No ( ); then go to question 2.

*If the answer is '**No' to question 1**, "*Are you sleeping well because you have been taking medication(s) for your sleep*?

Yes ( ); please specify the sleep medication name: ______________________
Dosage/ frequency: ______________________
No ( ); then go to question 4.

2. How long have you been having difficulty sleeping?
   less than 1 month ( )
   more than 1 month ( ); please specify duration: _____ years _____ months.

3. How frequently have you been experiencing difficulty sleeping?
   1 night per week ( )
   2 nights per week ( )
   3 nights per week ( )
   4 nights per week ( )
   5 nights per week ( )
   6 nights per week ( )
   every night ( )

4. During the past week, how often did you have to get up to use the bathroom?
   ( ) Not during the past month ( ) Less than once a week
   ( ) Once or twice a week ( ) Three or more times a week

5. Please rate by circling the current (i.e., **last week**) **severity** of your insomnia problem(s).

	None	Mild	Moderate	Severe	Very
a. Difficulty falling asleep	0	1	2	3	4
b. Difficulty staying asleep	0	1	2	3	4
c. Problem waking up too early	0	1	2	3	4

6. How **satisfied/ dissatisfied** are you with your current sleep pattern?

Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied
0	1	2	3	4

7. To what extent do you consider your sleep problem to **interfere** with your daily functioning (e.g. daytime fatigue, ability to function at work/ daily chores, concentration, memory, mood, etc.)

Not at all interfering	A little	Somewhat	Much	Very much interfering
0	1	2	3	4

8. How **noticeable** to others do you think your sleeping problem is in terms of impairing the quality of your life?

Not at all noticeable	A little	Somewhat	Much	Very much noticeable
0	1	2	3	4

9. How **worried/ distressed** are you about your current sleep problem?

Not at all worried	A little	Somewhat	Much	Very much worried
0	1	2	3	4

Appendix 3: Study 1 - Consent form

Participant ID:

THE UNIVERSITY OF WARWICK

CONSENT FORM

Exploring the definitions of sleep quality: A qualitative study with people with fibromyalgia, back pain and those without chronic pain.

Please initials in the boxes if you agree with the statement(s) below:

1. I have read and understood the Participant Information Sheet (Version 1 Date: 03.12.2013) for this study. I have had the opportunity to consider the information, ask questions and all questions have been answered satisfactorily.	
2. I agree to take part in the study and I understand that taking part in this study is entirely voluntary and I have the rights to withdraw at anytime without giving any reason.	
3. I agree to being interviewed and the interview is being audio-taped.	
4. I agree to be contacted to check and validate the themes extracted from the analysis.	
5. I agree that anonymous quotes from the interview may be used in the write-up of the study and may be published.	
6. I would like to receive a summary of the findings of this study.	
7. I agree to be contacted to participate in the future study.	

Participant's name	Participant's signature	Date
Researcher's name	Researcher's signature	Date

Appendix 4: Study 1 - The questionnaire booklet

THE UNIVERSITY OF WARWICK

Participant ID:

THE QUESTIONNAIRE BOOKLET

Exploring the definitions of sleep quality: A qualitative study with people with fibromyalgia, back pain and those without chronic pain

Please try your best to complete all sections of this booklet. There is no right or wrong answer. Do not spend too much time on each items or statements.

A. *Demographics*

1. Age :
2. Gender : ( ) Male ( ) Female
3. Weight : _________ kg *or* _________ pounds *or* ________ stone
4. Height : _________ cm *or* _________ feet _______ inches
7. Current employment status : ( ) Paid work ( ) Unpaid work ( ) Studying ( ) On sick leave ( ) Unemployed ( ) Retired ( ) Medically retired ( ) Other: _____________

11. What are the treatments you are currently taking? : ____

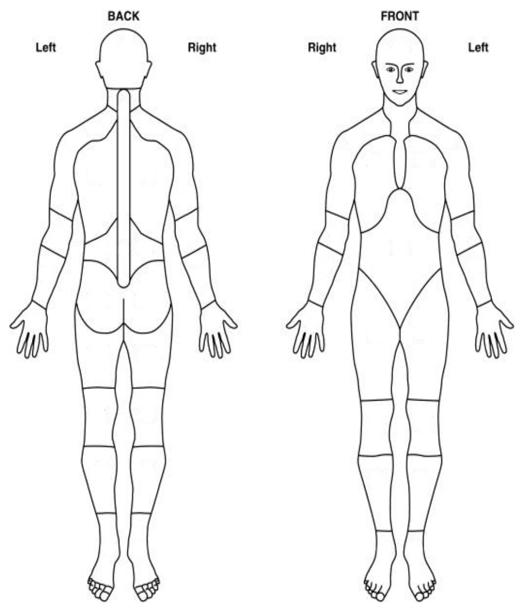
    ____

12. What is the pain like? : ( ) Constant ( ) Recurrent ( ) Intermittent: comes and goes ( ) Seasonal
13. Have you been giving a formal diagnosis? : ( ) Yes; please specify ___________________________ ( ) No
14. How long have you been having pain? : _________ year(s) ___________ month(s)
15. Any other illnesses? : (Please state)

    ____

B. Body Manikins

Shade in the diagram any pain that has lasted for 1 day or longer in the last week.



C. BPI

"Imagine a scale from 0 to 10, with 0 as "No pain at all" and 10 as "Pain as bad as you can imagine". Please use this scale and circle the number to answer the following items:

No pain at all	0	1	2	3	4	5	6	7	8	9	10	Pain as bad as you can imagine

1. Please rate your pain by telling me the one number that best describes your pain **at its worst in the last 24 hours**	0 1 2 3 4 5 6 7 8 9 10
2. Please rate your pain by telling me the one number that best describes your pain a**t its least in the last 24 hours**	0 1 2 3 4 5 6 7 8 9 10
3. Please rate your pain by telling me the one number that best describes your pain **on the average**	0 1 2 3 4 5 6 7 8 9 10
4. Please rate your pain by telling me the one number that tells how much pain you have **right now**	0 1 2 3 4 5 6 7 8 9 10

Imagine a scale that has 0 as "does not interfere" and 10 as "completely interfere". Please use this scale to answer the following items by circling the number that best describes how, during the past week, your pain has interfered with different aspects of your life:

Does not interfere	0	1	2	3	4	5	6	7	8	9	10	Completely interfere

5. General activity	0 1 2 3 4 5 6 7 8 9 10
6. Mood	0 1 2 3 4 5 6 7 8 9 10
7. Walking ability	0 1 2 3 4 5 6 7 8 9 10
8. Normal work (including bot work outside the home and housework)	0 1 2 3 4 5 6 7 8 9 10
9. Relationship with other people	0 1 2 3 4 5 6 7 8 9 10
10. Sleep	0 1 2 3 4 5 6 7 8 9 10
11. Enjoyment with life	0 1 2 3 4 5 6 7 8 9 10

D. DBAS

Several statements reflecting people's belief and attitudes about sleep are listed below. Please indicate to what extent you personally disagree or agree with each statement. There is no right or wrong answer. For each statement, circle the number that corresponds to your own personal belief. Please respond to all items even though some may not apply to your own situation directly.

Strongly Disagree — Strongly Agree

0 1 2 3 4 5 6 7 8 9 10

1. I need 8 hours sleep to feel refreshed and function well during the day.	0	1	2	3	4	5	6	7	8	9	10
2. When I don't get proper amount of sleep on a given night, I need to catch up on the next day by napping or on the next night by sleeping longer.	0	1	2	3	4	5	6	7	8	9	10
3. I am concerned that chronic insomnia may have serious consequences on my physical health.	0	1	2	3	4	5	6	7	8	9	10
4. I am worried that I may lose control over my abilities to sleep.	0	1	2	3	4	5	6	7	8	9	10
5. After a poor night's sleep, I know that it will interfere with my daily activities on the next day.	0	1	2	3	4	5	6	7	8	9	10
6. In order to be alert and function well during the day, I believe I would be better off taking a sleeping pill rather than having a poor night's sleep.	0	1	2	3	4	5	6	7	8	9	10
7. When I feel irritable, depressed or anxious during the day, it is mostly because I did not sleep well the night before.	0	1	2	3	4	5	6	7	8	9	10
8. When I sleep poorly on one night, I know it will disturb my sleep schedule for the whole week.	0	1	2	3	4	5	6	7	8	9	10
9. Without an adequate night's sleep, I can hardly function the next day.	0	1	2	3	4	5	6	7	8	9	10
10. I can't ever predict whether I'll have a good or poor night's sleep	0	1	2	3	4	5	6	7	8	9	10
11. I have little ability to manage the negative consequences of disturbed sleep	0	1	2	3	4	5	6	7	8	9	10
12. When I feel tired, have no energy, or just seem not function well during the day, it is generally because I did not sleep well the night before	0	1	2	3	4	5	6	7	8	9	10
13. I believe insomnia is essentially the result of a chemical imbalance	0	1	2	3	4	5	6	7	8	9	10
14. I feel insomnia is running my ability to enjoy life and prevents me from doing what I want	0	1	2	3	4	5	6	7	8	9	10
15. Medication is probably the only solution to sleep problem	0	1	2	3	4	5	6	7	8	9	10

Strongly Disagree 0 1 2 3 4 5 6 7 8 9 10 Strongly Agree	
16. I avoid or cancel obligations (social, family) after a poor night's sleep	0 1 2 3 4 5 6 7 8 9 10
***Please continue to answer Statement 17-26 if you are an individual with pain. **You may skip Statement 17-26 if you are a Pain-free individual.**	
17. My insomnia is largely a result of the pain and there is nothing I can do about it.	0 1 2 3 4 5 6 7 8 9 10
18. With the pain, I can never get myself comfortable in bed.	0 1 2 3 4 5 6 7 8 9 10
19. The pain is always there when I try to have a good night's sleep.	0 1 2 3 4 5 6 7 8 9 10
20. When I am in pain, I simply can't get to sleep no matter how hard I try	0 1 2 3 4 5 6 7 8 9 10
21. I know I can't sleep through the night because the pain will wake me up	0 1 2 3 4 5 6 7 8 9 10
22. I get very annoyed when the pain wakes me up	0 1 2 3 4 5 6 7 8 9 10
23. Not sleeping well is going to make my pain worse the next day	0 1 2 3 4 5 6 7 8 9 10
24. I won't be able to cope with the pain if I don't sleep well.	0 1 2 3 4 5 6 7 8 9 10
25. Unless I get rid of the pain, I won't sleep well	0 1 2 3 4 5 6 7 8 9 10
26. The insomnia is taking away one of my few respites from pain	0 1 2 3 4 5 6 7 8 9 10

E. HADS

Read each statement and place " X " in the (   ) reply which comes closest to how you have been feeling in the past week. Choose only one response for each statement.

I feel tense or "wound up":
(   ) Most of the time.
(   ) A lot of time.
(   ) Time to time. Occasionally.
(   ) Not at all.

I still enjoy the things I used to enjoy:

(   ) Definitely as much.
(   ) Not quite so much.
(   ) Only a little.
(   ) Hardly at all.

I get a sort of frightened feelings as if something awful is about to happen:
(   ) Very definitely and quite badly.
(   ) Yes, but not too badly.
(   ) A little, but it doesn't worry me.
(   ) Not at all.

I can laugh and see the funny side of things:
(   ) As much as I always could.
(   ) Not quite so much now.
(   ) Definitely not so much now.
(   ) Not at all.

Worrying thoughts go through my mind:
(   ) A great deal of the time.
(   ) A lot of the time.
(   ) From time to time but not too often.
(   ) Only occasionally.

I feel cheerful:
(   ) Not at all.
(   ) Not often.
(   ) Sometimes.
(   ) Most of the time.

I can seat at ease and feel relaxed:
(   ) Definitely.
(   ) Usually.
(   ) Not often.
(   ) Not at all.

I feel as if I am slowed down:
(   ) Nearly all the time
(   ) Very often
(   ) Sometimes
(   ) Not at all

I get a sort of frightened feeling like 'butterflies' in the stomach:
(   ) Not at all.
(   ) Occasionally.
(   ) Quite often.
(   ) Very often.

I have lost interest in my appearance:

(   ) Definitely.
(   ) I don't take so much care I should.
(   ) I may not take quite as much care.
(   ) I take just as much care as ever.

I feel restless as if I have to be on the move:
(   ) Very much indeed.
(   ) Quite a lot.
(   ) Not very much.
(   ) Not at all.

I look forward with enjoyment to things:
(   ) As much as ever I did.
(   ) Rather less than I used to.
(   ) Definitely less than I used to.
(   ) Hardly at all.

I get sudden feelings of panic:
(   ) Very often indeed.
(   ) Quite often.
(   ) Not very often.
(   ) Not at all.

I can enjoy a good book or radio or TV programme:
(   ) Often.
(   ) Sometimes.
(   ) Not often.
(   ) Very seldom.

F. MFI

How have you felt lately?
We would like to get an idea of how you have been feeling lately. For example, the statement:
"I feel relaxed".

If you think that this is entirely **true**, that indeed you have been feeling relaxed, please place an **X** in the extreme left box; like this:

yes, that is true	x					no, that is not true

The more you **disagree** with the statement, the more you can place an **X** in the direction of "no, that is not true".

1 **I feel fit**

yes, that is true ☐☐☐☐☐ no, that is not true

2 **Physically I feel only able to do a little**

yes, that is true ☐☐☐☐☐ no, that is not true

3 **I feel very active**

yes, that is true ☐☐☐☐☐ no, that is not true

4 **I feel like doing all sorts of nice things**

yes, that is true ☐☐☐☐☐ no, that is not true

5 **I feel tired**

yes, that is true ☐☐☐☐☐ no, that is not true

6 **I think I do a lot in a day**

yes, that is true ☐☐☐☐☐ no, that is not true

7 **When I am doing something, I can keep my thoughts on it**

yes, that is true ☐☐☐☐☐ no, that is not true

8 **Physically I can take on a lot**

yes, that is true ☐☐☐☐☐ no, that is not true

9 **I dread having to do things**

yes, that is true ☐☐☐☐☐ no, that is not true

10 **I think I do very little in a day**

yes, that is true ☐☐☐☐☐ no, that is not true

11 **I can concentrate well**

yes, that is true ☐☐☐☐☐ no, that is not true

12 **I am rested**

yes, that is true ☐☐☐☐☐ no, that is not true

13 **It takes a lot of effort to concentrate on things**

yes, that is true ☐☐☐☐☐ no, that is not true

14 **Physically I feel I am in a bad condition**

yes, that is true ☐☐☐☐☐ no, that is not true

15 **I have a lot of plans**

yes, that is true ☐☐☐☐☐ no, that is not true

16 **I tire easily**

yes, that is true ☐☐☐☐☐ no, that is not true

17 **I get little done**

yes, that is true ☐☐☐☐☐ no, that is not true

18 **I don’t feel like doing anything**

yes, that is true ☐☐☐☐☐ no, that is not true

19 **My thoughts easily wander**

yes, that is true ☐☐☐☐☐ no, that is not true

20 **Physically I feel I am in an excellent condition**

yes, that is true ☐☐☐☐☐ no, that is not true

Appendix 5: Study 1 - Debriefing sheet

THE UNIVERSITY OF WARWICK

DEBRIEFING SHEET

Project tittle: **Exploring the definitions of sleep quality: A qualitative study with people with fibromyalgia, back pain and those without chronic pain.**

Thank you for your participation in the study. The objectives of the study are to explore the definitions of sleep quality among people with and without chronic pain and in what ways the judgement of sleep quality affects people's daytime functioning. We invited people with and without chronic pain to participate in the study. The existing literature suggests that sleep quality are defined by means of several measures such as polysomnography (PSG), self-report questionnaires, sleep diary and the subjective individuals' report about their sleep. However, research shows that there is no single consensus on the definitions of sleep quality and inconsistencies in different sleep quality measures. Therefore, we thought by gathering information and definitions deriving from individuals' perspective would give a comprehensive understanding of the sleep quality phenomenon that comes from people's own perceptions. Besides, it's the patients' predominant complaints that brought them to seek clinicians for the treatment. That's why, understanding the ways by which people represent their sleep quality may help researchers and health care providers to offer services that could improve their sleep problem. If you have any concern about your participation, please feel free to contact me on +44(0) 24765 73469 or via email F.Ramlee@warwick.ac.uk. Alternatively, you could contact my supervisor, Dr. Nicole K. Y. Tang on +44(0) 2476150556 or email: n.tang@warwick.ac.uk.

Do you have any further questions or feedbacks about your participation?

Thank you for your participation in the study.

Researcher's details:
Fatanah Ramlee
PhD student
Department of Psychology,
The University of Warwick,
CV4 7AL, UK
Tel: +44/0 24765 73469
Email: F.Ramlee@warwick.ac.uk

Appendix 6: Study 2 - Participant information sheet

THE UNIVERSITY OF WARWICK

Information Sheet

Understanding People's Definitions of Sleep Quality

Thank you for considering taking part in this study, which aims to investigate your personal definition of sleep quality. Please read the information below carefully and if you have any questions about the study not answered by this information sheet feel free to ask the experimenter for further details.

Aims of the study
Sleep quality is a subjective concept that varies between people. This study would like to use a quantitative approach to investigate the structural components of this concept.

What do you have to do if you agree to take part?
If you sign up for the study, you will be asked to complete a questionnaire and perform a computer task in a single session of approximately 40 minutes. The session will take place at H0.91.

The questionnaire will ask you several questions about yourself and your sleep pattern. It will provide us some basic demographic and sleep information for the analysis of the data.

The computer task will involve you being shown sets of 2 scenarios. You will be asked to read and compare the two scenarios, and then choose one that describes a night of better sleep quality.

Ethical Approval
The protocol of the study has been grant full ethical approval by the DR@W Umbrella Ethics committee (reference number: 44/13-14). Participation is totally voluntary and you are free to withdraw from the study anytime without having to give a reason for doing so and without jeopardising your rights or your participation in future studies. All information collected in this study will be anonymised and kept confidential in accordance with the Data Protection Act 1998.

Investigators of this project are Dr. Adam Sanborn, Dr. Nicole Tang and Ms. Fatanah Ramlee. Their contact details are provided below. Please feel free to get in touch with any of them should you require further information.

Dr. Adam Sanborn (Psychology)
02476 151 354
a.n.sanborn@warwick.ac.uk

Dr. Nicole Tang (Psychology)
02476 150 556
n.tang@warwick.ac.uk

Ms. Fatanah Ramlee (Psychology)
02476 573 469
F.Ramlee@warwick.ac.uk

Appendix 7: Study 2 - Consent form

Consent Form

Understanding People's Definitions of Sleep Quality

Please read the statements below and initial in the boxes on the right if you agree with them.

1. I have read and understood the Information Sheet for this study. I have had the opportunity to consider the information, ask questions and all questions have been answered satisfactorily.	
2. I agree to take part in the study and I understand that taking part in this study is entirely voluntary and I can withdraw at anytime without giving any reason.	

______________________	______________________	____________
Participant's name	Participant's signature	Date
______________________	______________________	____________
Researcher's name	Researcher's signature	Date

Appendix 8: Study 2 - The questionnaire booklet

Please try your best to complete all sections of this questionnaire. There is no right or wrong answer. Do not spend too much time on each items or statements.

A. Demographics

1. Age :
2. Gender : (   ) Male   (   ) Female
3. Weight : _________ kg *or* _________ pounds *or* ________ stone
4. Height : _________ cm *or* _________ feet _______ inches
5. Ethnic origins :
   (   ) White
   (   ) White Irish
   (   ) Asian or Asian British: Chinese
   (   ) Asian or Asian British: Indian
   (   ) Asian or Asian British: Pakistani
   (   ) Asian or Asian British: Asian other
   (   ) Black or Black British
   (   ) British Mixed
   (   ) Other: ___________________
6. First language? :
   (   ) English
   (   ) Other: ___________________

B. Typical sleep pattern

1. During the past week, what time did you normally go to bed? ______ PM or ______ AM
2. During the past week, what time did you normally rise from bed? ______ AM or _____ PM
3. During the week, how long (in minutes) did it take you to fall asleep on a typical night?
   _______ minutes
4. During the past week, how many times were you woken up from sleep on a typical night? And how long (in minutes) were these awakenings in total?
   I usually woke up ________ times a night,
   and the total length of these awakenings was approximately _________ minutes.
5. During the past week, how much sleep did you get on a typical night?
   _____ hours ____ minutes

C. Sleeping Problem

1. Please rate by circling the current (i.e., **3 months**) **severity** of your sleeping problem(s), if you have any.

	None	Mild	Moderate	Severe	Very
a. Difficulty falling asleep	0	1	2	3	4
b. Difficulty staying asleep	0	1	2	3	4
c. Problem waking up too early	0	1	2	3	4

2. How **satisfied/ dissatisfied** are you with your current sleep pattern?

Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied
0	1	2	3	4

3. To what extent do you consider your sleep problem to **interfere** with your daily functioning (e.g. daytime fatigue, ability to function at work/ daily chores, concentration, memory, mood, etc.)

Not at all interfering	A little	Somewhat	Much	Very much interfering
0	1	2	3	4

4. How **noticeable** to others do you think your sleeping problem is in terms of impairing the quality of your life?

Not at all noticeable	A little	Somewhat	Much	Very much noticeable
0	1	2	3	4

5. How **worried/ distressed** are you about your current sleep problem?

Not at all worried	A little	Somewhat	Much	Very much worried
0	1	2	3	4

Appendix 9: Study 3[5] - Participant information sheet


Experiment 1 & 2 3: Participant Information Sheet

Project Title: Sleep, physical activity and pain inhibition in a healthy population

We would like to invite you to take part in this study for a research project looking at the association between sleep, physical activity and pain inhibition. Joining the study is entirely voluntary and we would like you to understand why the research is being done and what it would involve. If you decide to take part, you are still free to withdraw at any time and without giving a reason.

Please note: To take part in this study, you must be fairly healthy with no known major medical or psychiatric or neurological conditions. This is because of the type of sensory testing that will be carried out to assess your pain sensitivity and pain threshold, if you have any concerns regarding this, please let us know.

Please log-on to SONA to book your timeslots. You need to book two timeslots - Part 1 and Part 2 for exactly a week apart! The password/invitation code for the study is *lionpanda.*

You are allocated 1 hour to complete this research experience. You will be required to book two 20 minutes sessions a week apart to complete the tasks and can use rest of the time during the week in your own time to complete the short daily sleep & activity diaries.

The testing sessions will be carried out in the Sleep & Pain Lab (H0.102). When you come for your first session, we will describe and go through the study with you. If you agree to take part, you will sign the consent form. You will then complete some questionnaires, sensory testing will be carried out, followed by a post-task questionnaire. After this, you will be told how to complete sleep & activity diaries for the week. Exactly a week later, you come back to the lab for the re-test session, again, you will complete some questionnaires, and sensory testing will be carried out, followed by a post-task questionnaire.

An explanation of some of the procedures in the study

Questionnaires & Diaries

Questionnaires will be computer-based and diaries will be paper-based.

Quantitative sensory testing

This will consist of sensory testing to assess your pain sensitivity and pain threshold. Specifically, we will use an instrument called an algometer to assess your Pressure Pain Threshold, this is the minimum force applied to a chosen site of your body (right forearm) till you feel the pain of the pressure sensation. While you are doing this, you will also be carrying out other tests. One of this is a physical task - holding a 5-6kgs weighted bag using your other arm. The other is a Cold Pressor task where you will be asked to keep your left hand in a container of water maintained at 4 degrees Celsius until a pain sensation is first reported.

The sensory testing and physical functioning may cause some discomfort, however, these tasks have been routinely used in research and clinical settings for pain assessment. It is important to know that you can stop the procedure at any time if it gets to an unpleasant level of discomfort. We are aiming to detect your pain threshold (the point at which pain begins to be felt), NOT your pain tolerance (how much pain you are able to handle or tolerate). Any pain sensation will only be temporary so it is very important to realise that you can stop the tests as soon as you feel any discomfort or pain.

For more information please contact F.Ramlee@warwick.ac.uk (Fatanah) or E.F.Afolalu@warwick.ac.uk (Esther).

CPM_PIS_v1 5/12/15

[5] Study 3 is part of sleep, physical activity and pain inhibition research.

Appendix 10: Study 3 - Consent form

Participant ID:

CONSENT FORM

Project Title: Sleep, physical activity and pain inhibition in a healthy population

Researchers: Fatanah Ramlee & Esther Afolalu

Please Initial

1) I confirm that I have read and understood the participant information sheet dated 5/12/15 (version 1) for the above project, which I may keep for my records and have had the opportunity to consider the information, ask questions and all questions have been answered satisfactorily.	
2) I agree to take part in the project and am willing to: *Complete study questionnaires, sleep and activity diaries, and take part in a CPM experiment.*	
3) I understand that my information will be held and processed for the following purposes: *Research findings may be published in journals, presented at conferences and shared anonymously with other researchers.* I understand that I will not be identified personally in any presentation of publication and only the research team will have access to my personal information.	
4) I understand that my data will be kept strictly confidential. However, in any situation that might put me or anyone else at risk of harm, the researcher may have to inform the appropriate authorities.	
5) I understand that my participation is totally voluntary and that I am free to withdraw at any time without giving any reason without being disadvantaged in any way.	

Name of Participant	Signature	Date
____	___________________	_______________
Name of Researcher taking consent	Signature	Date
____	___________________	_______________

Appendix 11: Study 3 - Questionnaires

Project Title: **Sleep, physical activity and pain inhibition in a healthy population**

Please try your best to complete all sections. There are no rights or wrong answers. Do not spend too much time on each item or statement.

Demographic

1. Age :
2. Date of birth :
3. Gender : ( ) Male ( ) Female ( ) Choose not to disclose
4. Weight : _________ kg *or* _________ pounds *or* ________ stone
5. Height : _________ cm *or* _________ feet _______ inches
6. Ethnic origins : ( ) White
   ( ) White Irish
   ( ) Asian or Asian British: Chinese
   ( ) Asian or Asian British: Indian
   ( ) Asian or Asian British: Pakistani
   ( ) Asian or Asian British: Asian other
   ( ) Black or Black British
   ( ) British Mixed
   ( ) Other: __________________
   ( ) Choose not to disclose
7. Do you smoke? : ( ) Yes; ___________ cigarettes per day
   ( ) Quit; When did you stop smoking? _______
   ( ) No
   ( ) Choose not to disclose
8. Do you drink? : ( ) Yes; typical alcohol consumption in a week:
   _______ units (pint of regular beer/lager/cider)
   _______ units (glass of wine)
   _______ units (single measure of spirits)
   ( ) No
   ( ) Choose not to disclose
9. Do you have chronic pain? : ( ) Yes
   ( ) No
10. Any other illnesses? : (Please state)

PSQI

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. During the past month, when have you usually gone to bed at night?
   USUAL BED TIME:

2. During the past month, how long (in minutes) has it usually take you to fall asleep each night?
   NUMBER OF MINUTES:

3. During the past month, when have you usually gotten up in the morning? USUAL GETTING UP TIME:

4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spend in bed.) HOURS OF SLEEP PER NIGHT:

For each of the remaining questions, check the one best response. Please answer all questions.

5. During the past month, how often have you had trouble sleeping because you…	**Not during the past month**	**Less than once a week**	**Once or twice a week**	**Three or more times a week**
a. Cannot get to sleep within 30 minutes.				
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 badly				
f. Feel too cold				
g. Feel too hot				
h. Had bad dreams				
i. Have pain				
j. Other reason(s), please describe:				
	Very good	**Fairly good**	**Fairly bad**	**Very bad**
6. During the past month, how would you rate your sleep quality overall?				

	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
7. During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?				
8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?				
	No problem at all	**Only a very slight problem**	**Somewhat of a problem**	**A very big problem**
9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?				
	No bed partner or roommate	**Partner/ roommate in other room**	**Partner in same room, but not same bed**	**Partner in same bed**
10. Do you have a bed partner or roommate?				
If you have a room mate or bed partner, ask him/her how often in the past month you have had:	**Not during the past month**	**Less than once a week**	**Once or twice a week**	**Three or more times a week**
a. Loud snoring				
b. Long pauses between breaths while asleep				
c. Legs twitching or jerking while you sleep				
d. Episodes of disorientation or confusion during sleep				
e. Other restlessness while you sleep; please describe:				

MEQ
Please select the answer that best describes you by circling the point value that best indicates how you have felt in recent weeks (i.e. in the past month).

1. *Approximately* what time would you get up if you were entirely free to plan for your day?
[5] 5.00am – 6.30am (0500-0600h)
[4] 6.30am – 7.45am (0630-0745h)
[3] 7.45am – 9.45am (0745-0945h)
[2] 9.45am – 11.00am (0945-1100)
[1] 11.00am – 12 noon (1100-1200h)

2. *Approximately* what time would you go to bed if you were entirely free to plan your evening?
[5] 8.00pm – 9.00pm (2000-2100h)
[4] 9.00pm – 10.15pm (2100-2215h)
[3] 10.15pm – 12.30am (2215-0030h)
[2] 12.30am – 1.45am (0030-0145h)
[1] 1.45am – 3.00am (0145-0300h)

3. If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?
[4] Not at all
[3] Slightly
[2] Somewhat
[1] Very much

4. How easy do you find it to get up in the morning (when you are not awakened unexpectedly)?
[1] Very difficult
[2] Somewhat difficult
[3] Fairly easy
[4] Very easy

5. How alert do you feel during the first half hour after you wake up in the morning?
[1] Not at all alert
[2] Slightly alert
[3] Fairly alert
[4] Very alert

6. How hungry do you feel during the first half hour after you wake up?
[1] Not at all hungry
[2] Slightly hungry
[3] Fairly hungry
[4] Very hungry

7. During the first half hour after you wake up in the morning, how do you feel?
[1] Very tired
[2] Fairly tired
[3] Fairly refreshed
[4] Very refreshed

8. If you had no commitments the next day, what time would you go to bed compared to your usual bedtime?
[4] Seldom or never later
[3] Less that 1 hour later
[2] 1-2 hours later
[1] More than 2 hours later

9. You have decided to do physical exercise. A friend suggests that you do this for one hour or twice a week, and the best time for him is between 7-8am (0700-0800h). Bearing in mind nothing but your own internal "clock", how do you think you would perform?
[4] Would be in a good form
[3] Would be in a reasonable form
[2] Would find it difficult
[1] Would find it very difficult

10. At *approximately* what time in the evening do you feel tired, and, as a result, in need of sleep?
[5] 8.00pm – 9.00pm (2000-2100h)
[4] 9.00pm – 10.15pm (2100-2215h)
[3] 10.15pm – 12.45am (2215-0045h)
[2] 12.45am – 2.00am (0045-0200h)
[1] 2.00am – 3.00am (0200-0300h)

11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last two hours. You are entirely free to plan your day. Considering only your "internal clock", which one of the four testing times would you choose?
[6] 8.00am – 10.00am (0800-1000h)
[4] 11.00am – 1.00pm (1100-1300h)
[2] 3.00pm – 5.00pm (1500-1700h)
[0] 7.00pm – 9.00pm (1900-2100h)

12 If you got into bed at 11pm (2300h), how tired would you be?
[0] Not at all tired
[2] A little tired
[3] Fairly tired
[5] Very tired

13 For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which one of the following are you most likely to do?
[4] Will wake up at usual time, but will not fall back asleep
[3] Will wake up at usual time and will doze off thereafter
[2] Will wake up at usual time, but will fall asleep again
[1] Will not wake up until later than usual

14 One night you have to remain awake between 4-6am (0400-0600h) in order to carry out a night watch. You have no time commitments the next day. Which one of the alternatives would suit you best?
[1] Would not go to bed until the watch is over
[2] Would take a nap before and sleep after
[3] Would take a good sleep before and nap after
[4] Would sleep only before the watch

15. You have two hours of hard physical work. You are entirely free to plan your day. Considering only your internal “clock”, which of the following times would you choose?
[4] 8.00am – 10.00am (0800-1000h)
[3] 11.00am – 1.00pm (1100-1300h)
[2] 3.00pm – 5.00pm (1500-1700h)
[1] 7.00pm – 9.00pm (1900-2100h)

16. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week. The best time for her is between 10-11pm (2200-2300h). Bearing in mind only your internal “clock”, how well do you think you would perform?
[1] Would be in good form
[2] Would be in reasonable form
[3] Would find it difficult
[4] Would find it very difficult

17. Suppose you can choose your own work hours. Assume that you work a five-hour day (including breaks), your job is interesting, and you are paid based on your performance. At approximately what time would you choose to begin?
[5] 5 hours starting between 4.00-8.00am (0400-0800h)
[4] 5 hours starting between 8.00-9.00am (0800-0900h)
[3] 5 hours starting between 9.00am-2.00pm (0900-1400h)
[2] 5 hours starting between 2.00-5.00pm (1400-1700h)
[1] 5 hours starting between 5.00pm-4.00am (1700-0400h)

18. At approximately what time of day do you usually feel your best?
[5] 5.00-8.00am (0500-0800h)
[4] 8.00-10.00am (0800-1000h)
[3] 10.00am-5.00pm (1000-1700h)
[2] 5.00-10.00pm (1700-2200h)
[1] 10.00pm-5.00am (2200-0500h)

19. One hears about “morning types” and “evening types”. Which one of these types do you consider yourself to be?
[6] Definitely a morning type
[4] Rather more a morning type than an evening type
[2] Rather more an evening type than a morning type
[1] Definitely an evening type

PCS

Instructions: Everyone experiences painful situations at some point in their lives. Such experiences may include headaches, tooth pain, joint or muscle pain. People are often exposed to situations that may cause pain such as illness, injury, dental procedures or surgery. We are interested in the types of thoughts and feelings that you have when you are in pain. Listed below are thirteen statements describing different thoughts and feelings that may be associated with pain. Using the following scale, please indicate the degree to which you have these thoughts and feelings when you are experiencing pain.

When I'm in pain….

	Not at all	**To a slight degree**	**To a moderate degree**	**To a great degree**	**All the time**
1. I worry all the time about whether the pain will end	0	1	2	3	4
2. I feel I can't go on	0	1	2	3	4
3. It's terrible and I think it's never going to get any better	0	1	2	3	4
4. It's awful and I feel it overwhelms me	0	1	2	3	4
5. I feel I can't stand it anymore	0	1	2	3	4
6. I become afraid that the pain will get worse	0	1	2	3	4
7. I keep thinking of other painful events	0	1	2	3	4
8. I anxiously want the pain to go away	0	1	2	3	4
9. I can't seem to keep it out of my mind	0	1	2	3	4
10. I keep thinking about how much it hurts	0	1	2	3	4
11. I keep thinking about how badly I want the pain to stop	0	1	2	3	4
12. There's nothing I can do to reduce the intensity of the pain	0	1	2	3	4
13. I wonder whether something serious may happen	0	1	2	3	4

BPI

Please use the scale below to answer the following questions:

No pain at all	0 1 2 3 4 5 6 7 8 9 10	Pain as bad as you can imagine

1. Please rate your pain by telling me the one number that best describes your pain **at its worst in the past week**	0 1 2 3 4 5 6 7 8 9 10
2. Please rate your pain by telling me the one number that best describes your pain **at its least in the past week**	0 1 2 3 4 5 6 7 8 9 10
3. Please rate your pain by telling me the one number that best describes your pain **on the average**	0 1 2 3 4 5 6 7 8 9 10
4. Please rate your pain by telling me the one number that tells how much pain you have **right now**	0 1 2 3 4 5 6 7 8 9 10

SSS

Using the 7-point scale below pick what best represents how you are feeling right now and note the corresponding number on the chart below.

Degree of Sleepiness	**Rating scale**
Feeling active, vital, alert, or wide awake	1
Functioning at high levels, but not at peak; able to concentrate	2
Awake, but relaxed; responsive but not fully alert	3
Somewhat foggy, let down	4
Foggy; losing interest in remaining awake; slowed down	5
Sleepy, woozy, fighting sleep; prefer to lie down	6
No longer fighting sleep, sleep onset soon; having dream-like thoughts	7
Asleep	x

POMS2 - Adult Short

Instructions: Below is a list of words that describe feelings that people have. Please read each word carefully, then circle the number that best describes *how you are feeling right now.*

	Not at all	A little	Moderately	Quite a bit	Extremely
Friendly	0	1	2	3	4
Tense	0	1	2	3	4
Angry	0	1	2	3	4
Worn out	0	1	2	3	4
Lively	0	1	2	3	4
Confused	0	1	2	3	4
Considerate	0	1	2	3	4
Sad	0	1	2	3	4
Active	0	1	2	3	4
Grouchy	0	1	2	3	4
Energetic	0	1	2	3	4
Panicky	0	1	2	3	4
Hopeless	0	1	2	3	4
Uneasy	0	1	2	3	4
Unable to concentrate	0	1	2	3	4
Fatigued	0	1	2	3	4

	Not at all	A little	Moderately	Quite a bit	Extremely
Helpful	0	1	2	3	4
Nervous	0	1	2	3	4
Miserable	0	1	2	3	4
Muddled	0	1	2	3	4
Bitter	0	1	2	3	4
Exhausted	0	1	2	3	4
Anxious	0	1	2	3	4
Good-natured	0	1	2	3	4
Helpless	0	1	2	3	4
Weary	0	1	2	3	4
Bewildered	0	1	2	3	4
Furious	0	1	2	3	4
Trusting	0	1	2	3	4
Bad-tempered	0	1	2	3	4
Worthless	0	1	2	3	4
Vigorous	0	1	2	3	4
Uncertain about things	0	1	2	3	4
Drained	0	1	2	3	4
Enthusiastic	0	1	2	3	4

Appendix 12: Study 3 - Sleep diary

Sleep Diary (On waking)
Please complete the following item upon waking in the morning (within 30 minutes of your wake up time).

Today's date	Wed 20/1/16							
1. What time did you get into bed?	10:15pm							
2. What time did you try to go to sleep?	11:30pm							
3. How long did it take you to fall asleep?	55 min.							
4. How many times did you wake up, not counting your final awakening?	3 times							
5. In total, how long did these awakenings last?	1 hour 10 min.							
6. What time was your final awakening?	6:35am							
7. What time did you get out of bed for the day?	7:20am							
8. How would you rate the quality of your sleep? 0 (very poor) ------------- 10 (very good)	6							
9. Comments (if applicable)	I have a cold							

You may use the guidelines below to clarify what is being asked for each item of the Sleep Diary

1) *What time did you get into bed?* Write the time that you got into bed. This may not be the time that you began "trying" to fall asleep.
2) *What time did you try to go to sleep?* Record the time that you began "trying" to fall asleep.
3) *How long did it take you to fall asleep?* Beginning at the time you wrote in question 2, how long did it take you to fall asleep.
4) *How many times did you wake up, not counting your final awakening?* How many times did you wake up between the time you first fell asleep and your final awakening.
5) *In total, how long did these awakenings last?* What was the total time you were awake between the time you first feel asleep and your final awakening. For example, if you woke 3 times for 20 minutes, 35 minutes, and 15 minutes, add them all up (20+35+15=70 or 1hr and 10min).
6) *What time was your final awakening?* Record the last time you woke up in the morning.
7) *What time did you get out of the bed for the day?* What time did you get out of the bed with no further attempt at sleeping? This may be different from your final awakening time (e.g. you may have woken up 6:35 am but did not get out of bed to start your day until 7:20 a.m.)
8) *How would you rate the quality of your sleep?* "Sleep quality" is your sense whether your sleep was poor or good on a scale of 0 to 10: 0 is very poor and 10 is very good.
9) *Comments* If you have anything that you would like to say that is relevant to your sleep feel free to write it here

Appendix 13: Study 3-Activity diary

1

Activity Diary (bedtime)
Please complete the following item before you go to bed.

Today's date	Tuesday 19/1/16							
How physically active have you been today? 0 1 2 3 4 5 6 7 8 9 10 Not at active very active	**e.g.** 5							
How much time did you spend doing the following activity during the day?								
Running 0 1 2 3 4 5 6 7 8 9 10 Not at all a lot of the time	5							
Walking 0 1 2 3 4 5 6 7 8 9 10 Not at all a lot of the time	4							
Standing 0 1 2 3 4 5 6 7 8 9 10 Not at all a lot of the time	4							
Sitting 0 1 2 3 4 5 6 7 8 9 10 Not at all a lot of the time	7							
Lying down/ resting 0 1 2 3 4 5 6 7 8 9 10 Not at all a lot of the time	6							
Other activities (e.g. swimming, cycling, playing sports, going to the gym etc.) 0 1 2 3 4 5 6 7 8 9 10 Not at all a lot of the time	3							
If you have taken any medication today, please write down the name and dosage.	Tramadol 50mg							

Appendix 14: Study 3 - Debriefing sheet


Experiment 1 & 2: DEBRIEFING SHEET

Project Title: Sleep, physical activity and pain inhibition in a healthy population

Poor sleep has been associated with numerous negative health outcomes and decrease quality of life. Previous studies have shown that poor sleep quality may aggravate pain, increase pain sensitivity through interfering with endogenous pain-inhibitory mechanism (e.g. conditioned pain modulation) and increasing disability and physical limitation. Although there is a general association between sleep, pain and physical activity, those associations are more complex than it seems. Different studies have used different methods to elicit conditioned pain modulation (CPM) response in healthy and clinical participants. The procedure used to elicit CPM response requires standardization and identification of factors that could affect CPM response. It is also possible that cognitive distraction could potentially influence the validity and reliability of CPM response. Hence the proposed study aims to further investigate association between sleep, engagement in physical activity, and CPM response. The study also examines the test-retest stability and reliability of two different conditioning stimuli used to elicit CPM and examine the effect of distraction stimuli on CPM response. Finally, the study examines factors (sleep quality, sleep disruption, chronotype and pain catastrophizing) that may influence variations in CPM response.

If you have any concern about your participation, please feel free to contact us via email F.Ramlee@warwick.ac.uk / E.F.Afolalu@warwick.ac.uk. Alternatively, you could contact our supervisor, Dr. Nicole K. Y. Tang n.tang@warwick.ac.uk. Thank you for your participation in the study.

References

Hermans, L., Van Oosterwijck, J., Goubert, D., Goudman, L., Crombez, G., Calders, P., & Meeus, M. (2015). Inventory of Personal Factors Influencing Conditioned Pain Modulation in Healthy People: A Systematic Literature Review. *Pain Practice*.

Moont, R., Pud, D., Sprecher, E., Sharvit, G., & Yarnitsky, D. (2010). 'Pain inhibits pain' mechanisms: Is pain modulation simply due to distraction?. *Pain*, *150*(1), 113-120.

Smith, M., Edwards, R., & McCann, U. (2007). The effects of sleep de-privation on pain inhibition and spontaneous pain in women. *Sleep*, *30*(4), 494-505.

Appendix 15: Study 4 - NHS's ethical approval letter

NHS
Health Research Authority
NRES Committee West Midlands - South Birmingham
Royal Standard Place
Nottingham
NG1 6FS

Tel: 0115 883 9428

21 July 2015

Miss Fatanah Ramlee
Department of Psychology
University of Warwick
Coventry
CV4 7AL

Dear Miss Ramlee

Study title:	**Sleep & Daytime Physical Activity in People with Chronic Pain**
REC reference:	**15/WM/0171**
IRAS project ID:	**169820**

Thank you for your letter of 21 July 2015. I can confirm the REC has received the documents listed below and that these comply with the approval conditions detailed in our letter dated 20 July 2015.

Documents received

The documents received were as follows:

Document	*Version*	*Date*
Covering letter on headed paper [From Fatanah Ramlee, University of Warwick]		21 July 2015
Participant consent form [Tracked & Clean]	4	21 July 2015
Response to Request for Further Information [Response to FO with additional conditions]		21 July 2015

Approved documents

The final list of approved documentation for the study is therefore as follows:

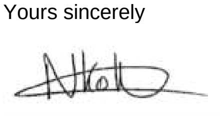
Document	*Version*	*Date*
Copies of advertisement materials for research participants [SDPA_Recruitment Poster]	1	30 March 2015
Covering letter on headed paper [Cover Letter]		22 April 2015
Covering letter on headed paper [From Fatanah Ramlee, University of Warwick]		21 July 2015

Evidence of Sponsor insurance or indemnity (non NHS Sponsors only) [University of Warwick Insurance Policy]		04 August 2014
IRAS Checklist XML [Checklist_16072015]		16 July 2015
Letters of invitation to participant [SDPA_Invitation]	1	15 January 2015
Other [Sleep Diary]	1	12 December 2014
Other [SDPA_Daily Diary]	1	12 December 2014
Other [flyer]	1	28 June 2015
Other [REC Amendment Cover Letter]	1	07 July 2015
Other [REC Further Information Cover Letter]	1	16 July 2015
Participant consent form [Tracked & Clean]	4	21 July 2015
Participant information sheet (PIS) [SDPA_PIS]	2	28 June 2015
REC Application Form [REC_Form_30042015]		30 April 2015
Research protocol or project proposal	1	09 March 2015
Response to Request for Further Information [Response to FO with additional conditions]		21 July 2015
Summary CV for Chief Investigator (CI)	1	02 April 2015
Summary CV for supervisor (student research) [CV Dr. Nicole Tang]	1	30 March 2015
Summary, synopsis or diagram (flowchart) of protocol in non technical language	1	18 March 2015
Validated questionnaire [SDPA_Questionnaire]	1	12 March 2015

You should ensure that the sponsor has a copy of the final documentation for the study. It is the sponsor's responsibility to ensure that the documentation is made available to R&D offices at all participating sites.

15/WM/0171	Please quote this number on all correspondence

Yours sincerely



Nicola Kohut
REC Assistant

E-mail: nrescommittee.westmidlands-southbirmingham@nhs.net

Copy to: Mrs Jane Prewett

Health Research Authority
NRES Committee West Midlands - South Birmingham
Royal Standard Place
Nottingham
NG1 6FS

Tel: 0115 883 9428

20 July 2015

Miss Fatanah Ramlee
Department of Psychology
University of Warwick
Coventry
CV4 7AL

Dear Miss Ramlee

Study title:	**Sleep & Daytime Physical Activity in People with Chronic Pain**
REC reference:	**15/WM/0171**
IRAS project ID:	**169820**

Thank you for your letter of 16 July 2015, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Chair.

We plan to publish your research summary wording for the above study on the HRA website, together with your contact details. Publication will be no earlier than three months from the date of this favourable opinion letter. The expectation is that this information will be published for all studies that receive an ethical opinion but should you wish to provide a substitute contact point, wish to make a request to defer, or require further information, please contact REC Manager, Penelope Gregory, nrescommittee.westmidlands-southbirmingham@nhs.net. Under very limited circumstances (e.g. for student research which has received an unfavourable opinion), it may be possible to grant an exemption to the publication of the study.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised, subject to the conditions specified below.

Conditions of the favourable opinion

The favourable opinion is subject to the following conditions being met prior to the start of the study:

1. Number the points in the consent form for clarity.

You should notify the REC in writing once all conditions have been met (except for site approvals from host organisations) and provide copies of any revised documentation with updated version numbers. The REC will acknowledge receipt and provide a final list of the approved documentation for the study, which can be made available to host organisations to facilitate their permission for the study. Failure to provide the final versions to the REC may cause delay in obtaining permissions.

Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

Management permission ("R&D approval") should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements.

Guidance on applying for NHS permission for research is available in the Integrated Research Application System or at http://www.rdforum.nhs.uk.

Where a NHS organisation's role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.

For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.

Sponsors are not required to notify the Committee of approvals from host organisations

Registration of Clinical Trials

All clinical trials (defined as the first four categories on the IRAS filter page) must be registered on a publically accessible database. This should be before the first participant is recruited but no later than 6 weeks after recruitment of the first participant.

There is no requirement to separately notify the REC but you should do so at the earliest opportunity e.g. when submitting an amendment. We will audit the registration details as part of the annual progress reporting process.

To ensure transparency in research, we strongly recommend that all research is registered but for non-clinical trials this is not currently mandatory.

If a sponsor wishes to request a deferral for study registration within the required timeframe, they should contact hra.studyregistration@nhs.net. The expectation is that all clinical trials will be registered, however, in exceptional circumstances non registration may be permissible with prior agreement from NRES. Guidance on where to register is provided on the HRA website.

It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

Ethical review of research sites

NHS sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

Non-NHS sites

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document	*Version*	*Date*
Copies of advertisement materials for research participants [SDPA_Recruitment Poster]	1	30 March 2015
Covering letter on headed paper [Cover Letter]		22 April 2015
Evidence of Sponsor insurance or indemnity (non NHS Sponsors only) [University of Warwick Insurance Policy]		04 August 2014
IRAS Checklist XML [Checklist_16072015]		16 July 2015
Letters of invitation to participant [SDPA_Invitation]	1	15 January 2015
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Other [REC Further Information Cover Letter]	1	16 July 2015
Participant consent form [SDPA_Consent Form]	3	16 July 2015
Participant information sheet (PIS) [SDPA_PIS]	2	28 June 2015
REC Application Form [REC_Form_30042015]		30 April 2015
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Summary CV for Chief Investigator (CI)	1	02 April 2015
Summary CV for supervisor (student research) [CV Dr. Nicole Tang]	1	30 March 2015
Summary, synopsis or diagram (flowchart) of protocol in non technical language	1	18 March 2015
Validated questionnaire [SDPA_Questionnaire]	1	12 March 2015

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

<u>Reporting requirements</u>

The attached document *"After ethical review – guidance for researchers"* gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

The HRA website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

User Feedback

The Health Research Authority is continually striving to provide a high quality service to all applicants and sponsors. You are invited to give your view of the service you have received and the application procedure. If you wish to make your views known please use the feedback form available on the HRA website:
http://www.hra.nhs.uk/about-the-hra/governance/quality-assurance/

HRA Training

We are pleased to welcome researchers and R&D staff at our training days – see details at http://www.hra.nhs.uk/hra-training/

15/WM/0171	Please quote this number on all correspondence

With the Committee's best wishes for the success of this project.

Yours sincerely

Professor Simon Bowman
Chair

Email: nrescommittee.westmidlands-southbirmingham@nhs.net

Enclosures: After ethical review – guidance for researchers

Copy to: Mrs Jane Prewett

Appendix 16: Study 4 - Participant information sheet

THE UNIVERSITY OF WARWICK

1

PARTICIPANT INFORMATION SHEET

Project Title: Sleep and Daytime Physical Activity in People with Chronic Pain

Researcher – Fatanah Ramlee *(BHSc. (Psychology)(Hons.), MHSc. Psychology)*
PhD Student – Department of Psychology

Academic Supervisor – Dr Nicole Tang *(D.Phil, C.Psychol)*
Associate Professor – Department of Psychology

We would like to invite you to take part in this study looking at sleep and daytime physical activity in people with chronic pain. Participation in the study is entirely voluntary. Before you decide, we would like you to understand why the research is being done and what it would involve. Please feel free to talk to others about the study if you wish. One of our team will also go through this information sheet with you to help you decide whether or not you would like to take part and answer any questions you may have. The first part of the Participant Information Sheet tells you the purpose of the study and what will happen to you if you take part. Part Two gives you more detailed information about how the study will be conducted. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. This is your copy of the information sheet to keep for future reference. Thank you for reading this.

What is the purpose of the study?
The study will examine the day-to-day association between sleep, pain and daytime physical activity.

Why have I been invited?
The study will investigate the link between sleep and physical activity in people suffering from chronic pain. We are inviting volunteers with chronic pain with or without a sleeping problem to help us better understand daily variations in sleep and daytime physical activity in individuals with chronic pain.

Do I have to take part?
It is up to you to decide whether or not to take part. If you do decide to take part, we will describe the study and go through this information sheet with you. If you agree to take part we will ask you to sign a consent form. If you decide to take part, you are still free to withdraw at any time and without giving a reason. We would like to assure you that your withdrawal from this study will not affect your opportunity to take part in future research or affect your standard hospital care in any way.

What will happen to me if I take part?

- If you meet our inclusion and exclusion criteria and have signed the consent form, you will be asked to monitor your sleep and daytime physical activity for 14 days.
- The monitoring will be carried out in your own natural living and sleeping environment.
- Before commencing the monitoring task, you will be given one-to-one training at the Sleep & Pain Laboratory, University of Warwick, during which the researcher will explain to you the purpose of the study and what you will need to do and demonstrate to you how to use the monitoring equipment and diary. You will also be asked to complete a questionnaire.

- You will be asked to wear an actiwatch, physical motion sensor (PAMSys) and to complete a daily diary three times a day throughout the duration of the study on waking (Diary 1), at the midpoint between Diary 1 and Diary 3 (Diary 2), and at bedtime (Diary 3). The timing of the daily diaries will be individually determined based on your self-report on your typical sleep-wake pattern.
- On day 8, you will be invited to come back to the lab to (1) download data from the first week, (2) change battery for the monitoring devices and (3) complete a cold pressor task. During this time, you will have an opportunity to discuss with the researcher any difficulties or problems during the first week of the monitoring.
- On day 15, you will come back to the lab for the final time to return the equipment and diaries. You will be debriefed about the research.

What will I have to do?
This will give you an explanation of some of the procedures in the study.

- *Sensors*: You will be required to wear two sensors, (1) actiwatch on your non-dominant wrist and (2) physical activity-monitoring sensor affixed with a chest strap. They should be worn continually except when coming into contact with water (bathing, swimming).
- *Daily Diary*: You will be asked to complete a daily diary three times a day for 14 days.
- *Cold Pressor Task*: You will be asked to complete a cold pressor task on Day 8. This task involves you submerging your hand in 4°C cold water until you feel the cold pain and retrieve your hand from the water. This procedure is safe and is nothing out of ordinary from daily experiences of washing your hands in the winter or holding a snowball with only bare hands. However, as a safety measure, you will be reminded that you can stop the task at any time if it gets to an unpleasant level of discomfort.

What are the possible disadvantages and risks of taking part?
The proposed study is a naturalistic observation study that does not involve any intervention or experimental manipulation. Participating in this study is totally voluntary. You will be informed in detail of the purpose and nature of the research and of your commitment and any inconvenience it may cause. You will be given sufficient time to make an informed decision about your participation. There are three potential disadvantages and risks been considered and on plan to address those are presented below:

- Firstly, the amount of effort and commitment required on your part to complete this study. You will be asked to complete two weeks of daily monitoring of your sleep and daytime physical activity. To minimise your burden, researchers have chosen equipment that is lightweight, non-intrusive and designed to be as comfortable as possible. The actiwatch and physical activity monitoring sensor are widely used in non-laboratory settings to record sleep-wake cycles and physical activity patterns.
- Secondly, the study will collect a lot of your personal information (e.g. demographics, sleep pattern, daily activity). Researchers will take several measures to protect your privacy and your data will be kept strictly confidential.
- Finally, this study also aims to examine the link between physical activity and pain. A cold pressor task is used to address this question. This is a valid way of obtaining pain information and would cause no tissue damage. This procedure is safe and is nothing out of ordinary from daily experiences of washing your hands in the winter or holding a snowball with only bare hands. However, as a safety measure, the researcher will remind you that you can stop the task at any time if it gets to an unpleasant level of discomfort.

What are the possible benefits of taking part?
There are no direct individual benefits to the participants. However, there may be some benefits in the future for others with chronic pain conditions as a consequence of discovery through this study. The results will also contribute to the increase of knowledge in the field of sleep quality and physical activity that could potentially inform the future design of clinical treatments for pain management.

Expenses and payments

- You will be reimbursed £20 to cover your travel expenses.
- The university also provides free disabled parking spaces available on campus just outside the Sleep & Pain Laboratory for blue-badge holders.

PART 2
What will happen if I don't want to carry on with the study?
You will be given sufficient time to address all the information about the study and make an informed decision. You will be able to make a free choice and can choose to opt out of any of the procedure or withdraw from the study at any time without giving a reason. You also have the choice to decline the use of any or all of your data that has already been collected.

Will my information be kept confidential?
Participation in the study will be kept strictly confidential. However, if there is any case that would put you or anyone else at risk of harm, the researcher may have to inform the appropriate authorities or GP. If this situation occurs the researcher will obtain consent from you and discuss possible options before informing to the authorities or GP.

What will happen to the results of this study?
When the results of the study are known they may be published in academic journals, presented at conferences, seminars, etc. When the findings are reported or presented, you will not be referred to in a way that could reveal your identity.

Who has reviewed this study?
All research carried out is looked at by an independent group of people called a research ethics committee to protect your interest.

- This study has been reviewed and given approval by the Research Ethics Committee of the Department of Psychology, The University of Warwick, Coventry CV4 7AL, UK.
- This study has been reviewed and given favourable opinion by NHS South Birmingham Research Ethics Committee (Ref. No: 15/WM/0171).

What if something goes wrong?
If you have a concern about any aspect of the study, please speak to the researcher who will do their best to answer your questions. If you remain unhappy, you can also contact the academic supervisor for this project.
If you would like to seek an independent advice or have any complaints about the research staff, conduct, etc. involved in a study and wish to complain formally, please contact the Director of Delivery Assurance, details as below:
Registrar's Office / Ms. Jo Horsburgh, Deputy Registrar, University of Warwick, Research Support Services, University House, Kirby Corner Road, Coventry, CV4 8UW.
Email: complaints@warwick.ac.uk / n.lynch@warwick.ac.uk
Telephone: 024 7652 2785. Fax: 024 7652 4751.

Further information and contact details
For more general information about the Sleep & Pain Lab, facilities and what we do, please visit our website http://www2.warwick.ac.uk/fac/sci/psych/research/lifespan/sleeplab
For more specific information and concerns about the study please contact the researcher or academic supervisor:

Researcher Fatanah Ramlee Department of Psychology University of Warwick Coventry, CV4 7AL Phone: +44(0) 24765 73469 E-mail: F.Ramlee@warwick.ac.uk	**Academic Supervisor** Dr. Nicole K. Y. Tang Department of Psychology University of Warwick Coventry, CV4 7AL. Phone: +44(0) 24761 50556 Email: n.tang@warwick.ac.uk

Appendix 17: Study 4 - Screening form

THE UNIVERSITY OF WARWICK

Project Title: Sleep and Daytime Physical Activity in People with Chronic Pain

PARTICIPANT SCREENING FORM

Participant's name : ____________________

Participant's telephone : ____________ Age: _______ Date of Birth: ____________

Participant's address : ____________________

Postcode : ____________ Gender: ____________

Participant's email : ____________________

Please tick (/) the following information that is applicable to your current situation:

	Aged between 18 and 65
	English speaking
	Presence of non-malignant pain (e.g. fibromyalgia, back pain, arthritis)
	Have been experiencing pain for 6 months or longer
	Being pregnant or a new parent
	Presence of a life threatening medical condition that would impede the ability to give consent and full participation in the study (e.g. cancer, HIV, neurological disorder, dementia etc.)
	Presence of acute pain (e.g. surgery, broken bones) or just general injury/pain that would limit participant's normal sleep pattern and daily activity.
	Diagnosis of learning disability, severe psychiatric illness, or physical disability (e.g. visual impairment)
	Wheelchair dependent
	Has a cardiac pacemaker and/or history of cardiovascular disorder
	Shift worker with irregular sleep pattern
	Diagnosis of sleep disorders (e.g., narcolepsy, Periodic Limb Movement Syndrome (PLMS)/ Restless Legs Syndrome (RLS), sleep apnoea)
	Currently enrolled in clinical studies, drug trial or is scheduled to receive an injection/ a surgery during the duration of the study
	Currently enrolled in an insomnia/ pain management programme or is scheduled to start such treatment during the duration of the study
	Has drug and/or alcohol misuse
	History of fainting or seizures
	History of frostbite, Reynaud's phenomenon (hands get white, then blue, on exposure to cold, then red on warming)
	Open cut or sore on hand to be immersed
	Fracture of limb to be immersed

Sleep & Daytime Physical Activity_Screening_v1 12/12/14

Appendix 18: Study 4 - Consent form

THE UNIVERSITY OF WARWICK

REC Reference: 15/WM/0171
Participant ID:

CONSENT FORM

Project Title: Sleep and Daytime Physical Activity in People with Chronic Pain
Researcher: Fatanah Ramlee

Please Initial

1) I confirm that I have read and understood the participant information sheet dated 28/06/15 (version 2) for the above project, which I may keep for my records and have had the opportunity to consider the information, ask questions and all questions have been answered satisfactorily.	
2) I agree to take part in the project and am willing to: *Complete study questionnaires, carry out monitoring procedures and take part in a cold pressor task.*	
3) I understand that my information will be held and processed for the following purposes: *Research findings may be published in journals, presented at conferences and shared anonymously with other researchers.* I understand that I will not be identified personally in any presentation of publication and only the research team will have access to my personal information.	
4) I understand that relevant sections of my medical notes and data collected during the study, may be looked at by individuals from Department of Psychology University of Warwick, from regulatory authorities or from the NHS Trust, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records.	
5) I understand that my data will be kept strictly confidential. However, in any situation that might put me or anyone else at risk of harm, the researcher may have to inform the appropriate authorities or my GP.	
6) I understand that my participation is totally voluntary and that I am free to withdraw at any time without giving any reason without being disadvantaged in any way.	
7) I agree to be contacted by the Warwick Sleep and Pain Lab regarding future studies.	
8) I would like to receive a summary of the findings of this study when available.	

Name of Participant	Signature	Date
______________________	______________	____________
Name of Researcher taking consent	Signature	Date
______________________	______________	____________

Sleep & Daytime Physical Activity_Consent Form_v4 21/07/15

Appendix 19: Study 4 - The questionnaire booklet

THE UNIVERSITY OF WARWICK

Participant ID:

THE QUESTIONNAIRE BOOKLET

Project Title: Sleep and Daytime Physical Activity in People with Chronic Pain

Please try your best to complete all sections of this booklet. There are no rights or wrong answers. Do not spend too much time on each item or statement.

A. Demographics

1. Age : _________ Date of birth: ________________
2. Gender : ( ) Male ( ) Female
3. Weight : _________ kg *or* _________ pounds *or* ________ stone
4. Height : _________ cm *or* _________ feet _______ inches
5. Ethnic origin : ( ) White
( ) White Irish
( ) Asian British: Chinese
( ) Asian British: Indian
( ) Asian British: Pakistani
( ) Asian British: Asian other
( ) Black British
( ) British Mixed
( ) Other: __________________
6. Current relationship status : ( ) Single ( ) Living with partner
( ) Married ( ) Separating
( ) Divorced ( ) Widowed
( )Other: ___________________
7. Number of children : ______
8. Living arrangement : ( ) Living alone
( ) With spouse or partner
( ) With spouse/ partner and children
( ) With family member(s)
( ) With friend(s)/ roommate(s)
( )Other: ___________________
9. Current employment status : ( ) Paid work- full time ( ) Unpaid work- full time
( ) Paid work- part time ( ) Unpaid work- part time
( ) Studying ( ) On sick leave
( ) Unemployed ( ) Retired
( ) Medically retired ( ) Other: _____________
10. Highest educational qualification : ( ) No formal education ( ) Primary
( ) Secondary ( ) Diploma
( ) Degree ( ) Postgraduate
( ) Other: ___________________
11. Do you smoke? : ( ) Yes; ___________ cigarettes per day
( ) Quit; When did you stop smoking? _______
( ) No

12. Do you drink? : ( ) Yes; typical alcohol consumption in a week:
_______ units (pint of regular beer/lager/cider)
_______ units (glass of wine)
_______ units (single measure of spirits)

( ) No

13. Have you been giving a formal diagnosis for your pain? : ( ) Yes; please specify ___________________________
( ) No

14. What is the pain like? : ( ) Constant
( ) Recurrent
( ) Intermittent: comes and goes
( ) Seasonal

15. How long have you been having pain? : _________ year(s) ___________ month(s)

Please shade in the area(s) on the diagram (Body manikins- page 3 in this booklet) where your pain is usually located.

16. Have you ever had any of these treatments for your pain? :

( ) Medication	( ) Surgery
( ) Physiotherapy	( ) Hydrotherapy
( ) Acupuncture	( ) Exercise
( ) Massage	( ) TENS
( ) Injection	( ) Self-help
( ) Support group	( ) Psychological treatment
( ) Other: __________________	

17. Which of the above treatments you are currently receiving? : ____

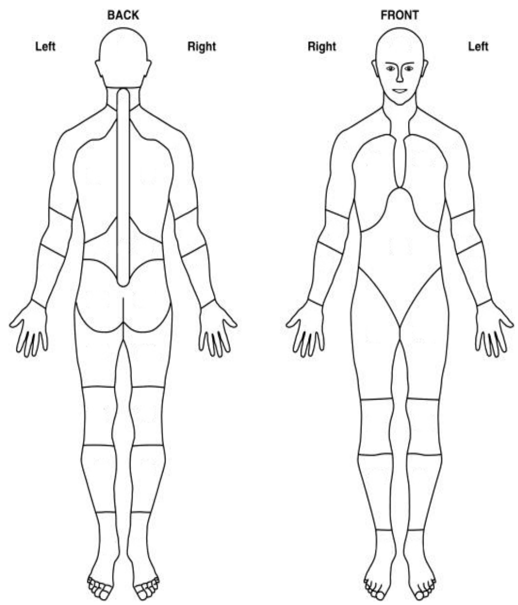
____

18. Do you have any other illnesses/ medical diagnosis? : (Please state)
____

19. Are you right- or left-handed? : ( ) Right handed
( ) Left handed

B. Body Manikins

Please shade in the areas on the diagram where your pain is usually located.



C. BPI

Please use the scale below to answer the following questions:

No pain at all ——— 0 1 2 3 4 5 6 7 8 9 10 ——— Pain as bad as you can imagine

1. Please rate your pain by telling me the one number that best describes your pain **at its worst in the past week**	0	1	2	3	4	5	6	7	8	9	10
2. Please rate your pain by telling me the one number that best describes your pain **at its least in the past week**	0	1	2	3	4	5	6	7	8	9	10
3. Please rate your pain by telling me the one number that best describes your pain **on the average**	0	1	2	3	4	5	6	7	8	9	10
4. Please rate your pain by telling me the one number that tells how much pain you have **right now**	0	1	2	3	4	5	6	7	8	9	10

Please use the scale below to answer the following question, how has your pain interfered with different aspect of your life?

Does not interfere ——— 0 1 2 3 4 5 6 7 8 9 10 ——— Completely interfere

5. General activity	0	1	2	3	4	5	6	7	8	9	10
6. Mood	0	1	2	3	4	5	6	7	8	9	10
7. Walking ability	0	1	2	3	4	5	6	7	8	9	10
8. Normal work (including both work outside the home and housework)	0	1	2	3	4	5	6	7	8	9	10
9. Relationship with other people	0	1	2	3	4	5	6	7	8	9	10
10. Sleep	0	1	2	3	4	5	6	7	8	9	10
11. Enjoyment with life	0	1	2	3	4	5	6	7	8	9	10

D. ISI

Please answer the following questions with reference to your sleep in the last 3 months.

1. During the last 3 months, what time did you normally go to bed? ________PM or _______AM

2. During the last 3 months, what time did you normally rise from bed? _______AM or ______PM

3. During the last 3 months, how long (in minutes) did it take you to fall asleep on a typical night? ________ minutes

4. During the last 3 months, how many times were you woken up from sleep on a typical night? And how long (in minutes) were these awakenings in total?

   I usually woke up ________ times a night, and the total length of these awakenings was approximately _________ minutes.

5. During the last 3 months, how much sleep did you get on a typical night? _____ hours _____ minutes

6. Did you have any difficulty sleeping in the last 3 months?
   Yes ( ) No ( )

*If the answer is '**Yes' to question 6**, "*Are you taking any medication(s) for your sleep*?"
Yes ( ); Please specify the sleep medication name: ______________________________
Dosage/ frequency: ____
No ( ); then go to question 7.

*If the answer is '**No' to question 6**, "*Are you sleeping well because you have been taking medication(s) for your sleep*?
Yes ( ); please specify the sleep medication name: ______________________________
Dosage/ frequency: ____
No ( ); then go to **section E** (**ESS**).

7. How long have you been having difficulty sleeping? ________ years ______ months.

8. How frequently have you been experiencing difficulty sleeping?
   1 night per week ( )
   2 nights per week ( )
   3 nights per week ( )
   4 nights per week ( )
   5 nights per week ( )
   6 nights per week ( )
   every night ( )

9. Please rate by circling the current **severity** of your insomnia problem(s).

	None	Mild	Moderate	Severe	Very
a. Difficulty falling asleep	0	1	2	3	4
b. Difficulty staying asleep	0	1	2	3	4
c. Problem waking up too early	0	1	2	3	4

10. How **satisfied/ dissatisfied** are you with your current sleep pattern?

Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied
0	1	2	3	4

11. To what extent do you consider your sleep problem to **interfere** with your daily functioning (e.g. daytime fatigue, ability to function at work/ daily chores, concentration, memory, mood, etc.)

Not at all interfering	A little	Somewhat	Much	Very much interfering
0	1	2	3	4

12. How **noticeable** to others do you think your sleeping problem is in terms of impairing the quality of your life?

Not at all noticeable	A little	Somewhat	Much	Very much noticeable
0	1	2	3	4

13. How **worried/ distressed** are you about your current sleep problem?

Not at all worried	A little	Somewhat	Much	Very much worried
0	1	2	3	4

E. <u>ESS</u>

How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired? This refers to your usual way of life in recent times (i.e. last 3 months). Even if you have not done some of these things recently, try to work out how they would have affected you. Please tick (/) the following boxes to choose the most appropriate number for each situation.

Situation	**Would never doze** **0**	**Slight chance of dozing** **1**	**Moderate chance of dozing** **2**	**High chance of dozing** **3**
Sitting and reading				
Watching TV				
Sitting, inactive in a public place (e.g., theatre or a meeting)				
As a passenger in a car for an hour without a break				
Lying down in the afternoon to rest when circumstances permit.				
Sitting and talking to someone				
Sitting quietly after lunch without alcohol				
In a car, while stopped for a few minutes in the traffic				

F. MEQ

Please select the answer that best describes you by circling the point value that best indicates how you have felt in recent weeks (i.e. last 3 months).

1. *Approximately* what time would you get up if you were entirely free to plan for your day?
   [5] 5.00am – 6.30am (0500-0600h)
   [4] 6.30am – 7.45am (0630-0745h)
   [3] 7.45am – 9.45am (0745-0945h)
   [2] 9.45am – 11.00am (0945-1100)
   [1] 11.00am – 12 noon (1100-1200h)

2. *Approximately* what time would you go to bed if you were entirely free to plan your evening?
   [5] 8.00pm – 9.00pm (2000-2100h)
   [4] 9.00pm – 10.15pm (2100-2215h)
   [3] 10.15pm – 12.30am (2215-0030h)
   [2] 12.30am – 1.45am (0030-0145h)
   [1] 1.45am – 3.00am (0145-0300h)

3. If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?
   [4] Not at all
   [3] Slightly
   [2] Somewhat
   [1] Very much

4. How easy do you find it to get up in the morning (when you are not awakened unexpectedly)?
   [1] Very difficult
   [2] Somewhat difficult
   [3] Fairly easy
   [4] Very easy

5. How alert do you feel during the first half hour after you wake up in the morning?
   [1] Not at all alert
   [2] Slightly alert
   [3] Fairly alert
   [4] Very alert

6. How hungry do you feel during the first half hour after you wake up?
   [1] Not at all hungry
   [2] Slightly hungry
   [3] Fairly hungry
   [4] Very hungry

7. During the first half hour after you wake up in the morning, how do you feel?
   [1] Very tired
   [2] Fairly tired
   [3] Fairly refreshed
   [4] Very refreshed

8. If you had no commitments the next day, what time would you go to bed compared to your usual bedtime?
   [4] Seldom or never later
   [3] Less that 1 hour later
   [2] 1-2 hours later
   [1] More than 2 hours later

9. You have decided to do physical exercise. A friend suggests that you do this for one hour or twice a week, and the best time for him is between 7-8am (0700-0800h). Bearing in mind nothing but your own internal "clock", how do you think you would perform?
   [4] Would be in a good form
   [3] Would be in a reasonable form
   [2] Would find it difficult
   [1] Would find it very difficult

10. At *approximately* what time in the evening do you feel tired, and, as a result, in need of sleep?
    [5] 8.00pm – 9.00pm (2000-2100h)
    [4] 9.00pm – 10.15pm (2100-2215h)
    [3] 10.15pm – 12.45am (2215-0045h)
    [2] 12.45am – 2.00am (0045-0200h)
    [1] 2.00am – 3.00am (0200-0300h)

11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last two hours. You are entirely free to plan your day. Considering only your "internal clock", which one of the four testing times would you choose?
    [6] 8.00am – 10.00am (0800-1000h)
    [4] 11.00am – 1.00pm (1100-1300h)
    [2] 3.00pm – 5.00pm (1500-1700h)
    [0] 7.00pm – 9.00pm (1900-2100h)

12 If you got into bed at 11pm (2300h), how tired would you be?
   [0] Not at all tired
   [2] A little tired
   [3] Fairly tired
   [5] Very tired

13 For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which one of the following are you most likely to do?
[4] Will wake up at usual time, but will not fall back asleep
[3] Will wake up at usual time and will doze off thereafter
[2] Will wake up at usual time, but will fall asleep again
[1] Will not wake up until later than usual

14 One night you have to remain awake between 4-6am (0400-0600h) in order to carry out a night watch. You have no time commitments the next day. Which one of the alternatives would suit you best?
[1] Would not go to bed until the watch is over
[2] Would take a nap before and sleep after
[3] Would take a good sleep before and nap after
[4] Would sleep only before the watch

15. You have two hours of hard physical work. You are entirely free to plan your day. Considering only your internal "clock", which of the following times would you choose?
[4] 8.00am – 10.00am (0800-1000h)
[3] 11.00am – 1.00pm (1100-1300h)
[2] 3.00pm – 5.00pm (1500-1700h)
[1] 7.00pm – 9.00pm (1900-2100h)

16. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week. The best time for her is between 10-11pm (2200-2300h). Bearing in mind only your internal "clock", how well do you think you would perform?
[1] Would be in good form
[2] Would be in reasonable form
[3] Would find it difficult
[4] Would find it very difficult

17. Suppose you can choose your own work hours. Assume that you work a five-hour day (including breaks), your job is interesting, and you are paid based on your performance. At approximately what time would you choose to begin?
[5] 5 hours starting between 4.00-8.00am (0500-0800h)
[4] 5 hours starting between 8.00-9.00am (0800-0900h)
[3] 5 hours starting between 9.00am-2.00pm (0900-1400h)
[2] 5 hours starting between 2.00-5.00pm (1400-1700h)
[1] 5 hours starting between 5.00pm-4.00am (1700-0400h)

18. At approximately what time of day do you usually feel your best?
[5] 5.00-8.00am (0500-0800h)
[4] 8.00-10.00am (0800-1000h)
[3] 10.00am-5.00pm (1000-1700h)
[2] 5.00-10.00pm (1700-2200)
[1] 10.00pm-5.00am (2200-0500h)

19. One hears about "morning types" and "evening types". Which one of these types do you consider yourself to be?
[6] Definitely a morning type
[4] Rather more a morning type than an evening type
[2] Rather more an evening type than a morning type
[1] Definitely an evening type

G. DBAS

Several statements reflecting people's belief and attitudes about sleep are listed below. Please indicate to what extent you personally disagree or agree with each statement. There is no right or wrong answer. For each statement, circle the number that corresponds to your own personal belief. Please respond to all items even though some may not apply to your own situation directly.

Strongly Disagree											Strongly Agree
	0	1	2	3	4	5	6	7	8	9	10
1. I need 8 hours sleep to feel refreshed and function well during the day.	0	1	2	3	4	5	6	7	8	9	10
2. When I don't get proper amount of sleep on a given night, I need to catch up on the next day by napping or on the next night by sleeping longer.	0	1	2	3	4	5	6	7	8	9	10
3. I am concerned that chronic insomnia may have serious consequences on my physical health.	0	1	2	3	4	5	6	7	8	9	10
4. I am worried that I may lose control over my abilities to sleep.	0	1	2	3	4	5	6	7	8	9	10
5. After a poor night's sleep, I know that it will interfere with my daily activities on the next day.	0	1	2	3	4	5	6	7	8	9	10
6. In order to be alert and function well during the day, I believe I would be better off taking a sleeping pill rather than having a poor night's sleep.	0	1	2	3	4	5	6	7	8	9	10
7. When I feel irritable, depressed or anxious during the day, it is mostly because I did not sleep well the night before.	0	1	2	3	4	5	6	7	8	9	10
8. When I sleep poorly on one night, I know it will disturb my sleep schedule for the whole week.	0	1	2	3	4	5	6	7	8	9	10
9. Without an adequate night's sleep, I can hardly function the next day.	0	1	2	3	4	5	6	7	8	9	10
10. I can't ever predict whether I'll have a good or poor night's sleep	0	1	2	3	4	5	6	7	8	9	10
11. I have little ability to manage the negative consequences of disturbed sleep	0	1	2	3	4	5	6	7	8	9	10
12. When I feel tired, have no energy, or just seem not function well during the day, it is generally because I did not sleep well the night before	0	1	2	3	4	5	6	7	8	9	10
13. I believe insomnia is essentially the result of a chemical imbalance	0	1	2	3	4	5	6	7	8	9	10
14. I feel insomnia is ruining my ability to enjoy life and prevents me from doing what I want	0	1	2	3	4	5	6	7	8	9	10
15. Medication is probably the only solution to sleep problem	0	1	2	3	4	5	6	7	8	9	10
16. I avoid or cancel obligations (social, family) after a	0	1	2	3	4	5	6	7	8	9	10

Strongly Disagree 0 1 2 3 4 5 6 7 8 9 10 Strongly Agree	
poor night's sleep	
17. My insomnia is largely a result of the pain and there is nothing I can do about it.	0 1 2 3 4 5 6 7 8 9 10
18. With the pain, I can never get myself comfortable in bed.	0 1 2 3 4 5 6 7 8 9 10
19. The pain is always there when I try to have a good night's sleep.	0 1 2 3 4 5 6 7 8 9 10
20. When I am in pain, I simply can't get to sleep no matter how hard I try	0 1 2 3 4 5 6 7 8 9 10
21. I know I can't sleep through the night because the pain will wake me up	0 1 2 3 4 5 6 7 8 9 10
22. I get very annoyed when the pain wakes me up	0 1 2 3 4 5 6 7 8 9 10
23. Not sleeping well is going to make my pain worse the next day	0 1 2 3 4 5 6 7 8 9 10
24. I won't be able to cope with the pain if I don't sleep well.	0 1 2 3 4 5 6 7 8 9 10
25. Unless I get rid of the pain, I won't sleep well	0 1 2 3 4 5 6 7 8 9 10
26. The insomnia is taking away one of my few respites from pain	0 1 2 3 4 5 6 7 8 9 10

H. HADS

Read each statement and place " / " in the (   ) reply which comes closest to how you have been feeling in the past week. Choose only one response for each statement.

1. I feel tense or "wound up":
(   ) Most of the time.
(   ) A lot of time.
(   ) Time to time. Occasionally.
(   ) Not at all.

2. I still enjoy the things I used to enjoy:
(   ) Definitely as much.
(   ) Not quite so much.
(   ) Only a little.
(   ) Hardly at all.

3. I get a sort of frightened feelings as if something awful is about to happen:
(   ) Very definitely and quite badly.
(   ) Yes, but not too badly.
(   ) A little, but it doesn't worry me.
(   ) Not at all.

4. I can laugh and see the funny side of things:
(   ) As much as I always could.
(   ) Not quite so much now.
(   ) Definitely not so much now.
(   ) Not at all.

5. Worrying thoughts go through my mind:
(   ) A great deal of the time.
(   ) A lot of the time.
(   ) From time to time but not too often.
(   ) Only occasionally.

6. I feel cheerful:
(   ) Not at all.
(   ) Not often.
(   ) Sometimes.
(   ) Most of the time.

7. I can sit at ease and feel relaxed:
(   ) Definitely.
(   ) Usually.
(   ) Not often.
(   ) Not at all.

8. I feel as if I am slowed down:
(   ) Nearly all the time
(   ) Very often
(   ) Sometimes
(   ) Not at all

9. I get a sort of frightened feeling like 'butterflies' in the stomach:
(   ) Not at all.
(   ) Occasionally.
(   ) Quite often.
(   ) Very often.

10. I have lost interest in my appearance:
(   ) Definitely.
(   ) I don't take so much care I should.
(   ) I may not take quite as much care.
(   ) I take just as much care as ever.

11. I feel restless as if I have to be on the move:
(   ) Very much indeed.
(   ) Quite a lot.
(   ) Not very much.
(   ) Not at all.

12. I look forward with enjoyment to things:
(   ) As much as ever I did.
(   ) Rather less than I used to.
(   ) Definitely less than I used to.
(   ) Hardly at all.

13. I get sudden feelings of panic:
(   ) Very often indeed.
(   ) Quite often.
(   ) Not very often.
(   ) Not at all.

14. I can enjoy a good book or radio or TV programme:
(   ) Often.
(   ) Sometimes.
(   ) Not often.
(   ) Very seldom.

I. *MFI*

How have you felt lately?
We would like to get an idea of how you have been feeling lately. For example, the statement:

"I feel relaxed".

If you think that this is entirely **true**, that indeed you have been feeling relaxed, please place an **X** in the extreme left box; like this:

yes, that is true	x					no, that is not true

The more you **disagree** with the statement, the more you can place an **X** in the direction of "no, that is not true".

1 **I feel fit**

yes, that is true						no, that is not true

2 **Physically I feel only able to do a little**

yes, that is true						no, that is not true

3 **I feel very active**

yes, that is true						no, that is not true

4 **I feel like doing all sorts of nice things**

yes, that is true						no, that is not true

5 **I feel tired**

yes, that is true						no, that is not true

6 **I think I do a lot in a day**

yes, that is true						no, that is not true

7 **When I am doing something, I can keep my thoughts on it**

yes, that is true						no, that is not true

8 **Physically I can take on a lot**

yes, that is true						no, that is not true

9 **I dread having to do things**

yes, that is true						no, that is not true

10 **I think I do very little in a day**

yes, that is true						no, that is not true

11 **I can concentrate well**

yes, that is true ☐ ☐ ☐ ☐ ☐ no, that is not true

12 **I am rested**

yes, that is true ☐ ☐ ☐ ☐ ☐ no, that is not true

13 **It takes a lot of effort to concentrate on things**

yes, that is true ☐ ☐ ☐ ☐ ☐ no, that is not true

14 **Physically I feel I am in a bad condition**

yes, that is true ☐ ☐ ☐ ☐ ☐ no, that is not true

15 **I have a lot of plans**

yes, that is true ☐ ☐ ☐ ☐ ☐ no, that is not true

16 **I tire easily**

yes, that is true ☐ ☐ ☐ ☐ ☐ no, that is not true

17 **I get little done**

yes, that is true ☐ ☐ ☐ ☐ ☐ no, that is not true

18 **I don’t feel like doing anything**

yes, that is true ☐ ☐ ☐ ☐ ☐ no, that is not true

19 **My thoughts easily wander**

yes, that is true ☐ ☐ ☐ ☐ ☐ no, that is not true

20 **Physically I feel I am in an excellent condition**

yes, that is true ☐ ☐ ☐ ☐ ☐ no, that is not true

J. TSK

Please answer the following questions according to your true feelings, not according to what others think you should believe. For each statement, circle the number that corresponds to your own personal belief.

Strongly Disagree 1 2 3 4 Strongly Agree	
1. I'm afraid that I might injure myself if I exercise.	1 2 3 4
2. If I were to overcome it, my pain would increase.	1 2 3 4
3. My body is telling me I have something dangerously wrong.	1 2 3 4
4. People aren't taking my medical condition seriously enough.	1 2 3 4
5. My accident has put my body at risk for the rest of my life.	1 2 3 4
6. Pain always means I have injured my body.	1 2 3 4
7. Simply being careful that I do not make any unnecessary movements is the safest thing I can do to prevent my pain from worsening.	1 2 3 4
8. I wouldn't have this much pain if there wasn't something potentially dangerous going on in my body.	1 2 3 4
9. Pain lets me know when to stop exercising so that I don't injure myself.	1 2 3 4
10. I can't do all the things normal people do because it's too easy for me to get injured.	1 2 3 4
11. No one should have to exercise when he/she is in pain.	1 2 3 4

K. POAM-P

Think about your usual approach to your daily activities and indicate below to what extent each of the statement applies to you.

Not at all — All the time 0 1 2 3 4					
1. I stop what I am doing when my pain starts to get worse.	0	1	2	3	4
2. When I am doing an activity I don't stop until it is finished.	0	1	2	3	4
3. I go back and forth between working and taking breaks when doing an activity.	0	1	2	3	4
4. I take on extra tasks when I am having a good pain day.	0	1	2	3	4
5. When I start an activity I think about how to split it into smaller part.	0	1	2	3	4
6. There are many activities that I avoid because they flare up my pain.	0	1	2	3	4
7. I make the most of my good pain days by doing more things.	0	1	2	3	4
8. When my pain starts to get worse I know it's time to stop what I am doing.	0	1	2	3	4
9. I do my activities at a slow and steady pace.	0	1	2	3	4
10. I keep doing what I am doing until my pain is so bad that I have to stop.	0	1	2	3	4
11. I avoid activities that I know will make my pain worse.	0	1	2	3	4
12. When I do an activity I stop after a while and then come back later to do more.	0	1	2	3	4
13. Most days my pain keeps me from doing much at all.	0	1	2	3	4
14. I go slower and work at a steady pace when I'm doing things.	0	1	2	3	4
15. Once I start an activity I keep going until it is done.	0	1	2	3	4
16. I limit my activities to the ones that I know will not make my pain worse.	0	1	2	3	4
17. When I do an activity I break it into small parts and do 1 part at a time.	0	1	2	3	4
18. I just ignore my pain and keep doing what I'm doing as long as I can.	0	1	2	3	4
19. Because of my pain most days I spend more time resting than doing activities.	0	1	2	3	4
20. I keep going until I can't stand the pain anymore.	0	1	2	3	4
21. Instead of doing an activity all at once I do a little bit at a time.	0	1	2	3	4
22. I don't start an activity if I know it will make my pain worse.	0	1	2	3	4
23. I do extra on days when my pain is less.	0	1	2	3	4
24. I remember to stop and take breaks when I'm doing an activity.	0	1	2	3	4
25. If I know that something will make my pain worse I don't do it	0	1	2	3	4

Not at all ... All the time 0 1 2 3 4					
anymore.					
26. When I do an activity I do the whole thing all at once.	0	1	2	3	4
27. Instead of doing the whole activity I divide it into small parts and do 1 part at a time.	0	1	2	3	4
28. I've cut back my activities by not doing the ones that make my pain worse.	0	1	2	3	4
29. When I do an activity I work for a while, take a break, and then go back to work again.	0	1	2	3	4
30. Some days I do a lot, other days I don't do much.	0	1	2	3	4

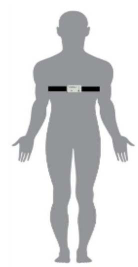
Thank you!

Appendix 20: Study 4 - Training manual

Training Manual

Sleep and Daytime Physical Activity in People with Chronic Pain

Welcome to Warwick Sleep and Physical Activity study! Thank you for your participation and incredible support you have given to this study. We have prepared a training manual that is designed to be a self-reference tool for when you are at home. This training manual describes the monitoring procedures and use of the devices in this study. It also describes the particular timing of the task you have to do. We hope you will have an enjoyable experience collecting data about your own sleep and daytime activity.

Time	What will I have to do?
Day	**Physical activity-monitoring sensor**   · The sensor (PAMSys logo facing away from the body and the arrow pointing to your left) is affixed with a chest strap and is worn continually during the day. · Do not remove the sensor from the strap. · Make sure the strap is snugly applied to your body. · There are two situations when you have to remove the sensor: 1) at bedtime: just before switching off the light 2) when bathing, shower, swimming or coming into any contact with water as it is not water-proof. · Wear the sensor as soon as possible after you have waken up in the morning (Preferably within 30minutes of your rise time). · Please press the event marker (on the actiwatch) when you put on and take off the sensor. · LED light indicator: ▪ Blink green every 3 seconds indicates measurement is activated ▪ Solid orange light indicates low battery power (This should not happen as the device is fully charged, but if it does, please contact the researcher) ▪ Red when battery power is too low to record data any further
Day & Night	**Actiwatch**  · Actiwatch is to be worn on the non-dominant wrist continually day & night throughout the study, except when bathing, shower, swimming or coming into any contact with water as it is not water-proof.

	· Press the event marker twice:
	    · At bedtime (When you switch off the lights and get ready to sleep)
	    · On waking (final awakening in the morning)

Day & Night	**Daily Diary & Sleep Diary** · The **daily diary** contains 11 items that ask you to rate your current state of mood, pain, tiredness, motivation, energy level, body condition, and sleepiness on a scale from 0 to 10, at the time when you are completing the diary. · The daily diaries are arranged into 14 envelopes: one for each day. Each envelope contains 3 diaries. Diary 1 is to be completed in the morning, Diary 2 at the midpoint between Diary 1 and Diary 2, and Diary 3 at bedtime. · The **Sleep Diary** contains 9 items asking about your experience of sleep. Information about seven nights (one week) can be recorded on one form. Please complete one column of the diary each morning, within 30 minutes after you wake up. *When to fill in these diaries?*  **Morning** (within 30 minutes of your wake up time) · Sleep Diary · Diary 1  **Midpoint between Diary 1 and Diary 3** · Diary 2  **Evening** (At bedtime; just before you switching off your lights) · Diary 3

Appendix 21: Study 4 - Monitoring schedule

Monitoring Schedule

Training Day	***Lab visit 1*** ➢ Training session and assessment	***Going home with:***	**Just before switching off the light**	***Bedtime:*** ➢ Remove the sensor ➢ Press the event marker
Day 1 → Day 7	***Wake:*** (within 30mins) ➢ Press event marker ➢ Fill out Sleep Diary & Diary 1 ➢ Put on the sensor	Time: **Midpoint between Diary 1 and Diary 3** ➢ Fill out Diary 2		***Bedtime:*** ➢ Fill out Diary 3 ➢ Remove the sensor ➢ Press the event marker
	Lab visit 2 ➢ Sensory Testing ➢ Download first week data			
Day 8 → Day 14	***Wake:*** (within 30mins) ➢ Press event marker ➢ Fill out Sleep Diary & Diary 1 ➢ Put on the sensor	Time: **Midpoint between Diary 1 and Diary 3** ➢ Fill out Diary 2		***Bedtime:*** ➢ Fill out Diary 3 ➢ Remove the sensor ➢ Press the event marker
Day 15	Thank You Thank You Thank You!!! **Lab visit 3** ➢ End of the study & debriefing			

Notes: Please remove the actiwatch & the sensor when bathing, shower, swimming or coming into contact with water.

Appendix 22: Study 4 - Sleep diary

Participant ID:

Sleep Diary

Today's date	Wed 7/1/15							
1. What time did you get into bed?	10:15pm							
2. What time did you try to go to sleep?	11:30pm							
3. How long did it take you to fall asleep?	55 min.							
4. How many times did you wake up, not counting your final awakening?	3 times							
5. In total, how long did these awakenings last?	1 hour 10 min.							
6. What time was your final awakening?	6:35am							
7. What time did you get out of bed for the day?	7:20am							
8. How would you rate the quality of your sleep? 0 (very poor) ------------- 10 (very good)	6							
9. Comments (if applicable)	I have a cold							

Sleep & Daytime Physical Activity_SleepDiary_v1 12/12/14

You may use the guidelines below to clarify what is being asked for each item of the Sleep Diary

1) *What time did you get into bed?* Write the time that you got into bed. This may not be the time that you began "trying" to fall asleep.
2) *What time did you try to go to sleep?* Record the time that you began "trying" to fall asleep.
3) *How long did it take you to fall asleep?* Beginning at the time you wrote in question 2, how long did it take you to fall asleep.
4) *How many times did you wake up, not counting your final awakening?* How many times did you wake up between the time you first fell asleep and your final awakening.
5) *In total, how long did these awakenings last?* What was the total time you were awake between the time you first feel asleep and your final awakening. For example, if you woke 3 times for 20 minutes, 35 minutes, and 15 minutes, add them all up (20+35+15=70 or 1hr and 10min).
6) *What time was your final awakening?* Record the last time you woke up in the morning.
7) *What time did you get out of the bed for the day?* What time did you get out of the bed with no further attempt at sleeping? This may be different from your final awakening time (e.g. you may have woken up 6:35 am but did not get out of bed to start your day until 7:20 a.m.)
8) *How would you rate the quality of your sleep?* "Sleep quality" is your sense whether your sleep was poor or good on a scale of 0 to 10: 0 is very poor and 10 is very good.
9) *Comments* If you have anything that you would like to say that is relevant to your sleep feel free to write it here.

Appendix 23: Study 4 - Daily diary (Diary 1, 2, and 3)

Today's date:

Diary 1 (On waking)

1. How would you rate the current level of **pain**?

0 1 2 3 4 5 6 7 8 9 10
No pain — Pain as bad as it could be

2. How would you rate your current **mood**?

0 1 2 3 4 5 6 7 8 9 10
Very bad — Very good

3. To what extent do you feel **tired** right now?

0 1 2 3 4 5 6 7 8 9 10
Not at all — Very much so

4. To what extent do you feel **fatigued** right now?

0 1 2 3 4 5 6 7 8 9 10
Not at all — Very much so

5. To what extent do you feel **sleepy** right now?

0 1 2 3 4 5 6 7 8 9 10
Not at all — Very much so

6. How would you rate your current **energy level**?

0 1 2 3 4 5 6 7 8 9 10
Very low — Very high

7. How would you rate your current **body condition**?

0 1 2 3 4 5 6 7 8 9 10
Fragile/weak — Healthy/strong

8. To what extent do you feel **motivated to accomplish tasks** right now?

0 1 2 3 4 5 6 7 8 9 10
Not at all — Very much so

9. To what extent do you feel **confident** that you can get things done?

0 1 2 3 4 5 6 7 8 9 10
Not at all — Very much so

10. To what extent do you feel you can **manage your pain right now**?

0 1 2 3 4 5 6 7 8 9 10
Very poorly — Very well

11 To what extent do you feel you can **manage your pain later today**?

0 1 2 3 4 5 6 7 8 9 10
Very poorly — Very well

Today's date:

Diary 2 (Midpoint)

1. How would you rate the current level of **pain**?

   0 1 2 3 4 5 6 7 8 9 10
   No pain — Pain as bad as it could be

2. How would you rate your current **mood**?

   0 1 2 3 4 5 6 7 8 9 10
   Very bad — Very good

3. To what extent do you feel **tired** right now?

   0 1 2 3 4 5 6 7 8 9 10
   Not at all — Very much so

4. To what extent do you feel **fatigued** right now?

   0 1 2 3 4 5 6 7 8 9 10
   Not at all — Very much so

5. To what extent do you feel **sleepy** right now?

   0 1 2 3 4 5 6 7 8 9 10
   Not at all — Very much so

6. How would you rate your current **energy level**?

   0 1 2 3 4 5 6 7 8 9 10
   Very low — Very high

7. How would you rate your current **body condition**?

   0 1 2 3 4 5 6 7 8 9 10
   Fragile/weak — Healthy/strong

8. To what extent do you feel **motivated to accomplish tasks** right now?

   0 1 2 3 4 5 6 7 8 9 10
   Not at all — Very much so

9. To what extent do you feel **confident** that you can get things done?

   0 1 2 3 4 5 6 7 8 9 10
   Not at all — Very much so

10. To what extent do you feel you can **manage your pain right now**?

    0 1 2 3 4 5 6 7 8 9 10
    Very poorly — Very well

11 To what extent do you feel you can **manage your pain later today**?

   0 1 2 3 4 5 6 7 8 9 10
   Very poorly — Very well

Today's date:

Diary 3 (Bedtime)

1. How would you rate the current level of **pain**?

0 1 2 3 4 5 6 7 8 9 10
No pain — Pain as bad as it could be

2. How would you rate your current **mood**?

0 1 2 3 4 5 6 7 8 9 10
Very bad — Very good

3. To what extent do you feel **tired** right now?

0 1 2 3 4 5 6 7 8 9 10
Not at all — Very much so

4. To what extent do you feel **fatigued** right now?

0 1 2 3 4 5 6 7 8 9 10
Not at all — Very much so

5. To what extent do you feel **sleepy** right now?

0 1 2 3 4 5 6 7 8 9 10
Not at all — Very much so

6. How would you rate your current **energy level**?

0 1 2 3 4 5 6 7 8 9 10
Very low — Very high

7. How would you rate your current **body condition**?

0 1 2 3 4 5 6 7 8 9 10
Fragile/weak — Healthy/strong

8. To what extent do you feel **motivated to accomplish tasks** right now?

0 1 2 3 4 5 6 7 8 9 10
Not at all — Very much so

9. To what extent do you feel **confident** that you can get things done?

0 1 2 3 4 5 6 7 8 9 10
Not at all — Very much so

10. To what extent do you feel you can **manage your pain right now**?

0 1 2 3 4 5 6 7 8 9 10
Very poorly — Very well

11 To what extent do you feel you can **manage your pain later**?

0 1 2 3 4 5 6 7 8 9 10
Very poorly — Very well

Appendix 24: Study 4 - Debriefing sheet

THE UNIVERSITY OF WARWICK

DEBRIEFING SHEET

Project Title: Sleep and Daytime Physical Activity in People with Chronic Pain

Thank you for your participation in the study. People with chronic pain (e.g. fibromyalgia, back pain) are reported to be less active than those without chronic pain in the general population. Numerous psychological factors have been associated with their relatively lower physical activity levels. A recent study has found a day-to-day relationship between sleep quality and physical activity. The study found that in the absence of any intervention, chronic pain patients spontaneously engaged in more daytime physical activity following a night of better sleep. The findings are interesting as it provides initial evidence to support the role of sleep in the regulation of daily physical activity. However, it is still not known what type of daytime physical activity chronic pain patients engage in following a better night of sleep and whether this increase in daytime physical activity is beneficial for pain regulation. Furthermore, sleep quality and chronic pain may interact with numerous psychophysiological factors to affect daytime physical activity. Hence, this study also aims to examine how day-to-day variations of sleep quality is associated with daytime physical activity and psychophysiological variables (e.g. pain, sleepiness) and whether the increased level of daytime physical activity has an effect on pain regulation. We hope the findings of this study would add to our understanding of the relationship between these important aspects of chronic pain.

If you have any concern about your participation, please feel free to contact me on +44(0) 24765 73469 or via email F.Ramlee@warwick.ac.uk. Alternatively, you could contact my supervisor, Dr. Nicole K. Y. Tang on +44(0) 2476150556 or email: n.tang@warwick.ac.uk.

Thank you for your participation in the study.

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