

UNIVERSITI TEKNOLOGI MARA

**THE EFFECT OF EXERCISE ON
SLEEP QUALITY IN OVERWEIGHT
AND OBESE: A SYSTEMATIC
REVIEW AND META ANALYSIS**

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MAHTAR**

MSc

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NURUL FARAH SHAFIQA BINTI MAHTAR

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of the requirements for the degree of
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CONFIRMATION BY PANEL OF EXAMINERS

I certify that a Panel of Examiners has met on 3 February 2026 to conduct the final examination of Nurul Farah Shafiqah bt Mahtar on her Master of Science thesis entitled “The Effect of Exercise on Sleep Quality in Overweight and Obese: A Systematic Review and Meta Analysis” in accordance with Universiti Teknologi MARA Act 1976 (Akta 173). The Panel of Examiners recommends that the student be awarded the relevant degree. The Panel of Examiners was as follows:

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I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Teknologi MARA. It is original and is the results of my own work, unless otherwise indicated or acknowledged as referenced work. This thesis has not been submitted to any other academic institution or non-academic institution for any degree or qualification.

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ABSTRACT

Background: The quality of sleep has a significant impact on emotional stability, cognitive performance, and physical healing. Individuals who are overweight or obese frequently have poor sleep quality. Evidence suggest that exercise is a beneficial measure for improving sleep quality by favorably impacting physiological systems involved in sleep regulation. Nevertheless, no meta-analysis has yet evaluated this research on overweight and obese individuals. **Objectives:** This study evaluates the effect of exercise on sleep quality in overweight and obese individuals through a systematic review and meta-analysis. **Methods:** Randomized controlled trials (2006–2023) that compared exercise groups with control groups were identified through searches of four electronic databases: PubMed, ScienceDirect, Scopus, and Web of Science. Subjective sleep outcomes were assessed using the Pittsburgh Sleep Quality Index (PSQI), while objective outcomes were obtained through actigraphy or polysomnography. The risk of bias was evaluated using TESTEX, and a random-effects model was employed in RevMan 5.4 for meta-analyses. **Results:** Exercise significantly enhanced subjective sleep quality in overweight and obese people, as determined by 32 trials (N = 2301) (lower PSQI scores, MD -1.80, 95% CI -2.55 to -1.05, $p < 0.00001$). The only objective sleep outcomes that showed a significant improvement were sleep efficiency and wake after sleep onset; total sleep time and sleep onset latency did not. **Conclusion:** Exercise helps overweight and obese individuals sleep better subjectively, but not objectively. Further research is needed to explore its effects on objective sleep parameters.

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LIST OF ABBREVIATIONS

Abbreviations

AIS	Athens Insomnia Scale
BMI	Body Mass Index
CRF	Corticotropin-releasing Factor
ISI	Insomnia Severity Index (ISI)
NREM	Non-Rapid Eye Movement
NSF	National Sleep Foundation
PLMD	Periodic Limb Movement Disorder
PROSPERO	International Prospective Register of Systematic Reviews
PSG	Polysomnography
PSQI	Pittsburgh Sleep Quality Inventory
RCT	Randomized Control Trial
REM	Rapid Eye Movement
SDB	Sleep Disordered Breathing
SE	Sleep Efficiency
SOL	Sleep Onset Latency
TESTEX	Tool for the Assessment of Study Quality and Reporting in Exercise
TST	Total Sleep Time
WASO	Wake After Sleep Onset

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Overweight and obesity have emerged as major concerns for the health of populations all over the world as their prevalence rates continue to rise around the globe. According to the World Health Organization (2025), in the year 2022, more than 2.5 billion adults were classed as being overweight, and more than 890 million of those adults were classified as being obese (World Health Organization, 2025). These statistics indicate the fact that excess body weight now affects almost a third of the adult population around the world, highlighting the relevance of this obesity problem as a serious public health concern today. Meanwhile, in Malaysia, recent data (2024) indicate that 30.5% of adults are classified as overweight, while 23.1% are obese, reflecting a similarly concerning national trend (National Health and Morbidity Survey (NHMS), 2024).

Numerous adverse health consequences, including cardiovascular diseases (Katta et al., 2021), type 2 diabetes (Boutari et al., 2023), along with certain types of cancer (Avgerinos et al., 2019), are linked to this concerning trend. Among the several medical conditions associated with being overweight or obese, poor sleep quality is an issue that is very alarming but is often overlooked. Throughout the past few decades, a pattern of insufficient sleep has been noticed in modern society, and it implies that this pattern and the obesity epidemic are related (Tasali et al., 2022). Short sleep duration is now being implicated as a new contributing factor for the emergence of obesity and its comorbidities (Gibson-Moore & Chambers, 2019).

Poor sleep quality is a multidimensional construct that can be assessed using both subjective and objective measures. Subjective sleep quality refers to an individual's perception of their sleep experience, including sleep satisfaction, restfulness, and disturbances, and is commonly assessed using validated instruments such as the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989). In contrast, objective sleep quality is evaluated using physiological and behavioral parameters such as sleep duration, sleep efficiency, sleep latency, and sleep architecture, typically measured through actigraphy or polysomnography (Chen et al., 2023). While subjective

measures capture perceived sleep experiences that are clinically meaningful, objective measures provide quantifiable indicators of underlying sleep physiology (Chen et al., 2023). Notably, discrepancies between subjective and objective sleep assessments are frequently reported, particularly among individuals with insomnia and obesity, suggesting that both dimensions should be considered when evaluating sleep outcomes (Buysse, 2014; Carney et al., 2012).

There is strong evidence that sleeping for less than 7 hours regularly has negative effects on one's health (St-Onge, 2017). Recent research by Jung et al. (2011) revealed that after 40 hours of sleep deprivation, subjects reported an increase in 24-hour energy expenditure, primarily because of a 32% increase at night (Jung et al., 2011). These sleep architectural disruptions not only worsen metabolic and hormonal imbalances, but they also hinder weight loss efforts by encouraging exhaustion, appetite dysregulation, and decreased physical activity.

Previous research has shown that sleep deprivation causes ghrelin, a hormone that stimulates hunger, to increase, while leptin, a hormone that makes individuals feel full, to decrease (Morselli et al., 2010; Van Cauter et al., 2008), which could imply that constantly getting less sleep could increase appetite, thus would lead to overeat. Furthermore, the probability of carrying out exercise is decreased for short sleepers due to fatigue experienced by them (Cooper et al., 2018a). Thus, it will increase the risk of obesity since they overconsumed and living a sedentary lifestyle. Moreover, insufficient sleep might also have an impact on energy balance by lowering energy expenditure from both exercise and non-exercise activity (Beccuti & Pannain, 2011). As leptin alone boosts energy expenditure, alterations in leptin during sleep loss would influence calorie intake as well as energy expenditure (Beccuti & Pannain, 2011).

Regular exercise plays a critical role in improving sleep patterns, particularly among individuals with overweight and obesity, through several interconnected physiological mechanisms. Excess adiposity is often associated with dysregulation of the hypothalamic–pituitary–adrenal (HPA) axis, elevated cortisol levels, and increased sympathetic nervous system activity, all of which contribute to poor sleep quality and disturbances in sleep architecture (van Dalsen & Markus, 2018). Exercise has been shown to mitigate these effects by reducing cortisol levels and enhancing parasympathetic activity, thereby promoting a more favorable physiological state for sleep (De Nys et al., 2022). In addition, exercise contributes to thermoregulatory processes, whereby the post-exercise decline in core body temperature facilitates sleep

onset and increases slow-wave sleep, which is often impaired in individuals with obesity (Kredlow et al., 2015). Collectively, these mechanisms suggest that exercise is an effective non-pharmacological strategy to improve sleep outcomes and address the bidirectional relationship between sleep disturbances and obesity.

Various types of exercise have been shown to enhance sleep quality, including resistance training, aerobic exercise, and mind-body interventions such as yoga and Pilates. The selection of these types of exercise in this study are based on their distinct physiological characteristics and their widespread application in both clinical and public health interventions. Resistance training has been proven to reduce comorbidities frequently linked to poor sleep quality, such as depression (Moraes et al., 2020) and cardiovascular disease (M. A. Williams et al., 2007). Moreover, according to a study, aerobic exercise can enhance sleep quality by 44.46% after 12 consecutive weeks (Sharif et al., 2015). Additionally, in a 6 months aerobic exercise program, demonstrated that both quantity and quality of their sleep greatly improved (Tan et al., 2016). Combined aerobic and resistance training, reflects real-world exercise prescriptions commonly used in obesity management and has been shown to produce superior improvements in body composition and metabolic health compared to aerobic or resistance training alone in overweight and obese populations (García-Hermoso et al., 2018). Furthermore, a study by Aibar-Almazán et al. (2019) reported that Pilates exercise led to significant improvements in subjective sleep quality, with results reaching a high level of statistical significance ($p < 0.001$) (Aibar-Almazán et al., 2019). Ultimately, exercise intervention, which is a non-pharmacological approach for reducing insomnia and enhancing sleep quality shows possible superiority and encouraging improvement; even so, these approaches must be widely used and implemented in the future (Xie et al., 2021).

While there is a growing number of publications about the effect of exercise on sleep quality in overweight and obese, there is still lack of information on good quality and adequate quantity of sleep for obese population especially during exercise regime. A systematic review and meta-analysis will allow for a rigorous synthesis of available data, helping to clarify the extent to which exercise interventions can improve sleep outcomes in overweight and obese populations. Targeting overweight and obese individuals allows for a more clinically meaningful evaluation of exercise interventions, as this group is both highly affected by sleep disturbances and likely to benefit from improvements in exercise. In addition, exercise interventions in this population may

yield greater observable effects on sleep outcomes due to their higher baseline risk of sleep impairment, thereby enhancing the sensitivity and relevance of pooled estimates in the meta-analysis. This analysis attempts to fill the gap in understanding the research pattern and trends regarding the relations between sleep, obesity, and exercise. Therefore, the primary objective of this analysis was to study the effect of exercise on sleep quality in overweight and obese populations by examining the available literature.

1.2 Problem Statement

Over recent years, exercise has shown improvement in overall health and sleep quality for participants who perform exercise and undergo training programs. Most of the studies is focusing on various populations, which is diabetes patients (Alarcón-Gómez et al., 2021), chronic insomnia patients (Yu et al., 2023), and postmenopausal women (Aibar-Almazán et al., 2019). All these studies demonstrates positive benefits on enhancing sleep quality after exercise intervention. According to a meta-analysis by Xie et al. (2021), adults' sleep quality can be effectively enhanced by both physical and mind-body exercises. The results did not, however, establish whether physical or mind-body exercise was better at enhancing sleep quality. Similar to this, a more recent meta-analysis by Yu et al. (2023) found that exercise improves patients with chronic insomnia's subjective sleep quality, but it was unable to determine the best type of exercise intervention (Yu et al., 2023). Despite all these studies examining the effects of exercise on sleep quality, none of these studies have particularly examined populations that are overweight or obese. These conflicting and uncertain findings highlight a significant gap in the literature and indicate for additional research to identify the types of exercise that can improve sleep quality for individuals who are overweight or obese. Hence, the purpose of this analysis is to use available literatures that has been published in scholarly publications to investigate how exercise affects the quality of sleep in populations that are overweight or obese.

1.3 Research Question

This study is set to answer the following research questions:

- a) How effective are exercises (aerobic, resistance, combined aerobic and resistance, and mind-body exercise) as compared to control group for improving subjective sleep quality in overweight and obese individuals?

- b) How effective are exercises (aerobic, resistance, combined aerobic and resistance, and mind-body exercise) as compared to control group for improving objective sleep quality (TST, SOL, SE, WASO) in overweight and obese individuals?
- c) Do different types of exercise interventions (aerobic, combined aerobic and resistance, mind-body) have varying effects on sleep quality in overweight and obese populations?
- d) Does body mass index (BMI) classification (overweight vs obese) influence subjective sleep quality outcomes differently in response to exercise interventions?
- e) Do sleep conditions (normal sleepers vs sleep disorder patients) influence the effectiveness of exercise interventions on improving subjective sleep quality in overweight and obese individuals?

1.4 Research Objective

This study embarks on the following objectives:

- a) To systematically evaluate the effect of exercise (aerobic, resistance, combined aerobic and resistance, and mind-body exercise) on subjective sleep quality in overweight and obese.
- b) To systematically evaluate the effect of exercise (aerobic, resistance, combined aerobic and resistance, and mind-body exercise) on objective sleep quality in overweight and obese.
- c) To compare the effectiveness of different types of exercise interventions (aerobic, combined aerobic and resistance, mind-body exercise) in improving sleep quality among overweight and obese individuals through subgroup meta-analysis.
- d) To examine whether BMI classification affects sleep quality outcomes differently among individuals who are overweight or obese, by using subgroup meta-analysis.
- e) To evaluate whether sleep disorders influence the effectiveness of exercise interventions on subjective sleep quality in overweight and obese individuals.

1.5 Research Hypotheses

- a) Meta-analysis demonstrates a significant effect of exercise (aerobic, resistance, combined aerobic and resistance, and mind-body exercise) on the subjective sleep quality in overweight and obese.
- b) Meta-analysis demonstrates a significant effect of exercise (aerobic, resistance, combined aerobic and resistance, and mind-body exercise) on the objective sleep quality (TST, SOL, SE, WASO) in overweight and obese.
- c) Subgroup meta-analysis demonstrates significant effects of all types of exercise (aerobic, combined aerobic and resistance, and mind-body exercise) on the subjective sleep quality when compared to control group.
- d) Subgroup meta-analysis demonstrates a significant effect of the exercise (aerobic, resistance, combined aerobic and resistance, and mind-body exercise) on subjective sleep quality in obese group when compared to overweight group.
- e) Subgroup meta-analysis demonstrates a significant effect of the exercise (aerobic, resistance, combined aerobic and resistance, and mind-body exercise) on subjective sleep quality in normal sleepers group when compared to sleep disorder group.

1.6 Significance of the study

The proposed study can provide insights into how exercise might mitigate various health risks. Obesity is a global health challenge associated with numerous medical conditions like cardiovascular diseases, diabetes, and sleep disorders, such as obstructive sleep apnea. Understanding the relationship between exercise and sleep quality can provide insights into how exercise might mitigate these health risks. Good sleep quality is essential for physical and mental health. If exercise can improve sleep quality in overweight and obese individuals, it can have broader positive effects on overall health, cognition, mood, and daily functioning. Moreover, if a positive relationship is found between exercise and sleep quality in overweight and obese individuals, healthcare professionals can develop interventions that emphasize exercise to improve sleep among this population. Furthermore, treating sleep disorders can be expensive, especially if it involves surgeries or long-term use of medications. If exercise can be a non-pharmacological and non-invasive method to improve sleep quality, it could provide a more cost-effective solution. Additionally, improved sleep can lead to

better mood and mental well-being. Understanding the effects of exercise on sleep can also provide insights into how to enhance the psychosocial aspects of overweight and obese individuals' lives. In summary, a study on this topic can provide valuable insights into how a simple intervention like exercise might offer multifaceted benefits for overweight and obese individuals, especially concerning their sleep quality. It has implications for healthcare strategies, public health campaigns, and individual well-being. The findings of this systematic review and meta-analysis have the potential to inform future research directions, guide healthcare practitioners in recommending evidence-based interventions, and contribute to the development of targeted exercise programs to improve sleep outcomes in individuals with overweight and obesity. This study is integral for advancing our understanding of the interplay between exercise and sleep quality in overweight and obesity and promoting holistic approaches to enhance overall health in this population.

1.7 Operational Term

1.7.1 Body Mass Index (BMI)

Body mass index (BMI) is calculated by dividing a person's weight in kilograms by their height in meters squared (kg/m^2) (World Health Organization, 2021). The resulting BMI value categorizes individuals into specific weight status categories, providing a standardized measure for assessing relative body weight and classifying individuals as underweight, normal weight, overweight, or obese based on established BMI ranges. As for this study, participants whom BMI above 25 (overweight and obese) will only be included for the analysis.

1.7.2 Sleep Quality

Sleep quality is defined as a multidimensional construct encompassing subjective and objective measures to assess the overall effectiveness, satisfaction, and restorative nature of an individual's sleep experience. Subjective components include self-reported perceptions of factors such as sleep latency, sleep duration, sleep efficiency, sleep disturbances, and overall satisfaction with sleep. Objective components involve quantifiable metrics obtained through methods such as polysomnography or actigraphy, providing information on sleep architecture, patterns, and disruptions. In this study, both assessments will be accepted for the analysis.

1.7.3 Sleep Efficiency (SE)

Sleep efficiency is operationally defined as the ratio of time spent asleep to the total time spent in bed, expressed as a percentage. It is calculated by dividing the total sleep duration (time spent asleep) by the total time spent in bed and multiplying the result by 100 (Ohayon et al., 2017). Sleep efficiency provides a quantitative measure of how effectively an individual utilizes their time in bed for sleep, with higher percentages indicating a more efficient sleep pattern and lower percentages suggesting increased wakefulness or sleep fragmentation during the designated sleep period. Sleep efficiency serves as a valuable metric for assessing the overall quality and effectiveness of sleep.

1.7.4 Sleep Latency

Sleep latency is operationally defined as the time duration it takes for an individual to transition from a fully awake state to the onset of sleep after initiating attempts to fall asleep. It is measured by recording the time elapsed from the moment the individual lies down in bed until the onset of sleep (Nelson et al., 2022). Sleep latency provides a measurable indicator of the ease or difficulty in transitioning from wakefulness to sleep.

1.7.5 Total Sleep Time (TST)

Total sleep time is operationally defined as the total amount of time an individual spends in a state of sleep during 24hours. It is measured by calculating the temporal interval between sleep onset (the moment when an individual falls asleep) and sleep offset (the moment when an individual wakes up) across consecutive sleep episodes within 24hours (C. Kline, 2013).

1.7.6 Wake After Sleep Onset (WASO)

Wake After Sleep Onset (WASO) is operationally defined as the total duration of wakefulness experienced by an individual after the initial onset of sleep and before final awakening (Krystal & Edinger, 2008a). It is measured by calculating the cumulative time spent awake during the sleep period, excluding the time taken to fall asleep initially (Krystal & Edinger, 2008a). For instance, a person's WASO is 15 minutes if they wake up once throughout the night and are awake for that entire 15 minutes. According to National Sleep Foundation, a WASO of 20 minutes or less is

believed to have good sleep quality, while WASO of 51 minutes or greater is considered to have poor sleep quality (Ohayon et al., 2017).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the literature review that supported the current study. The literature has been exhausted from relevant electronic resources that includes articles journals, published in English. The earliest range of publication was 1968 while the latest was 2025. Various journals have been used, amongst those are International Journal of Environmental Research and Public Health, Journal of Sleep Research, Journal of Physical Activity and Health, The Journal of Physiology, etc. Pubmed and ScienceDirect were some of the databases used to gain relevant information. The search keywords used were selected according to the research topic, including exercise, physical activity, quality of sleep, sleep disturbance, overweight and obese.

This chapter is made up of five sections. The first section explains the physiology of sleep. This section covers the purposes of sleep and stages of sleep. The second section discusses regarding sleep as a risk factor for overweight and obesity. The third section explains possible mechanism that linked sleep, overweight and obesity, and cardiometabolic health. The forth section reviews the literature related to modality of exercise that is suitable for this study. The fifth section explains the exercise characteristics and their impact on sleep quality. The sixth reviews the variations in exercise effects on sleep quality by BMI status. The seventh section explains the differential effects of exercise on sleep quality based on sleep status. The last section explains the difference between subjective and objective sleep quality.

2.2 Physiology of Sleep

A fundamental essential for good health is sleep. It has a crucial role in both physiological and psychological processes, such as neural activity, metabolism, hunger management, immunological response, and hormone regulation (Vincent et al., 2017). Different amounts of sleep are needed depending on the person and their age; generally, for adults, 7 to 9 hours each night is advisable for optimal physical and psychological well-being (Watson et al., 2015).

According to Petit et al. (2015), the awake cycle is intended for continuous glycogen breakdown, whereas sleep is a glycogenolytic process that refills glucose storage in neurons (Petit et al., 2015). This finding would suggest that sleep has endocrine effects on the brain apart from the hormonal control of metabolism and cellular waste disposal. Moreover, it has been hypothesized that this chain of events may be brought on by changes in body temperature, heart rate and heart rate variability, growth hormone secretion, cytokine concentrations, body composition, brain deduced neurotrophic factor secretion, mood and anxiety symptoms, central nervous system fatigue, increased energy expenditure rate, and fitness level improvements (Kredlow et al., 2015). Abel et al. (2013) suggested different fundamental purposes of sleep, which is to facilitate the storing and retention of memories. The authors propose that sleep-related patterns of neural oscillations activate the neurobiological mechanisms controlling synaptic plasticity and long-term potentiation (Abel et al., 2013).

The two phases of sleep that one's body cycles go through are REM (rapid eye movement) and NREM (non-rapid eye movement), which is further broken down into three stages, N1 N2, N3 (Dolezal et al., 2017). Movement of the eyes, brain wave patterns, and tone of muscles are all varies during each stage of sleep (Patel et al., 2022). All of these stages are cycled through by the body 4 to 6 times per night, with each cycle lasting an average of 90 minutes (Memar & Faradji, 2018). The majority of sleep, roughly 75%, occurs in the NREM phases, mostly in the N2 stage (Malik et al., 2018). Sleep stages progressed in the following sequence: N1, N2, N3, REM (Feinberg & Floyd, 1979).

N1 is the lightest stage of sleep, specifically it is the transitional period from wakefulness to sleep (Patel et al., 2022). The body is not completely relaxed during this stage, despite the muscle and brain activity begin to slow down with periods of small motions. Skeletal muscle exhibits muscle tone and breathing occur at a usual pace in this stage (Patel et al., 2022). Approximately 1 to 5 minutes, which 5% of the overall sleep period, are spent in this stage (Patel et al., 2022). In this stage of sleep, it is easy to wake people up, but if they are not bothered, they can rapidly shift into stage 2 of sleep.

N2 stage symbolizes deeper sleep as there is a decline in heart rate and body temperature (Patel et al., 2022). It can be identified by the existence of sleep spindles and K-complexes (Patel et al., 2022). Sleep spindles are known as small but able to produce intense waves of neuronal firing (Patel et al., 2022). It can cause calcium to

influx into cortical pyramidal cells in the anterior cingulate, insular cortices, superior temporal gyri, and thalamus (Patel et al., 2022). Synaptic plasticity is considered to rely on this mechanism (Patel et al., 2022). A number of studies demonstrate that sleep spindles are crucial for the consolidation of memory, particularly procedural and declarative memories (Antony et al., 2019). Long delta waves called K-complexes, which last for about a second, are believed to be the longest and most prominent of all brain waves (Patel et al., 2022). It has been demonstrated that K-complexes have a role in preserving consolidation of memories and sleep (Gandhi et al., 2022). Stage 2 sleep begins with a cycle that lasts around 25 minutes and gets longer with each subsequent cycle, making up approximately 45% of total sleep (Patel et al., 2022). Bruxism (tooth grinding) happens during this sleep stage (Patel et al., 2022).

N3 is often referred as slow-wave sleep (SWS) and it is believed to be the deepest sleep stage (Patel et al., 2022). It can be identified by a signal named delta wave, which have lower frequencies and higher amplitudes (Patel et al., 2022). It is the hardest for someone to wake up in this stage, and for certain individuals, even extremely loud noises (over 100 dB) may not awaken them (Patel et al., 2022). As people get older, they often spend greater time in N2 stage and less time in N3 stage (Patel et al., 2022). Despite the fact that this stage has the highest arousal threshold, if a person is awakened in this stage, they will experience sleep inertia, which is a brief period of mental confusion (Patel et al., 2022). According to cognitive testing, people who awaken during this stage typically experience mild cognitive impairment for 30 to 60 minutes (Hilditch et al., 2019). During this phase, the body recovers and regenerates tissues, develops bone and muscle, and boost the immune system (Patel et al., 2022). Additionally, this is the time when bedwetting, sleepwalking, and terrifying nightmares start to happen (El Shakankiry, 2011).

REM is not regarded as a peaceful sleep stage because it is related to dreaming (Patel et al., 2022). Although the EEG is identical to an awakened person, the skeletal muscles are atonic and immobile, with the exception of the eyes and the respiratory muscles, which continue to be active (Patel et al., 2022). Conversely, the respiratory pattern becomes increasingly inconsistent (Patel et al., 2022). This stage typically begins 90 minutes after people falling asleep, with each REM cycle becoming longer (Patel et al., 2022). Generally, the initial period lasts for 10 minutes, and the final one might last up to 60 minutes (Peever & Fuller, 2017). REM is the stage at which dreams, night terrors, and penile/clitoral tumescence happen (Patel et al., 2022).

2.3 Sleep As a Risk Factor for Overweight and Obesity

Along with the well-established diet, nutrition, and exercise, sleep disturbances and severe sleep restriction have been reported as distinct factors that may contribute to the rising incidence of overweight and obesity (Gibson-Moore & Chambers, 2019). An increasing collection of epidemiological studies reveals that getting less sleep is linked to a greater incidence of obesity and cardiometabolic diseases, such as type 2 diabetes, cardiovascular disease, and mortality (Koren et al., 2016). The documented connections between inadequate sleep and obesity (and related comorbidities) might be justified by reverse causality, as most of the research conducted in this field is cross-sectional, making it unclear which way the link is going (Koren et al., 2016). For instance, obesity is a recognized risk factor for diseases like sleep apnea and arthritis that can impair a person's ability to sleep (Cappuccio & Miller, 2017; Wu et al., 2014).

Prospective cohort studies provide stronger evidence for the temporal relationship between sleep duration and weight gain. Several systematic reviews and meta-analyses have consistently reported that short sleep duration is associated with an increased risk of both overweight and obesity in adults (Itani et al., 2017; Wu et al., 2014; Q. Zhou et al., 2019). The most current of these reviews, which contained 12 research, investigated whether there is a dose-response relationship between adult obesity prevalence and sleep length (Q. Zhou et al., 2019). The findings showed a reverse J-shaped relationship among both sleep length and incidence of obesity, with 7-8 hours per night of sleep having the least risk (Q. Zhou et al., 2019). Obesity risk increased considerably with short sleep duration, but not with extended sleep length (>8 hours per night) (Q. Zhou et al., 2019). Each hour less sleep is related to a 9% higher risk of obesity as compared to 7 hours per night (Q. Zhou et al., 2019). The fact that sleep length was self-reported was a drawback of almost all research evaluated in the review. Additionally, even though the meta-analysis took into account a number of confounding factors, remaining or unobserved variables could not be excluded, and several potential variables (such as sleep apnea and the quality of sleep) were not evaluated (Q. Zhou et al., 2019). According to Q. Zhou et al. (2019), despite these drawbacks, results from prospective cohort studies continue to be the strongest proof to assess the long-term effects of sleep duration on obesity (Q. Zhou et al., 2019). In a similar vein, several recently published systematic reviews and meta-analyses of prospective cohort studies have investigated the long-term impact of sleep duration on

child obesity risk, with all of them finding statistically significant associations between insufficient sleep in children and subsequent risk of overweight and obesity (Fatima et al., 2015; Li et al., 2017; Wu et al., 2017). Ultimately, these longitudinal studies suggest that obtaining enough sleep may be crucial for preventing childhood and adult for getting overweight and obese.

In recent years, experimental sleep research has become more prevalent, and these studies offer valuable insight into the causative role of insufficient sleep in overweight, obesity and its associated comorbidities. According to systematic reviews and meta-analyses of randomized controlled trials in this field, sleep restriction may be a contributing factor in elevated total calorie consumption and weight gain (Capers et al., 2015; Zhu et al., 2019). The most recent of these analyses examined the effects of sleep restriction versus normal sleep on markers related to hunger and metabolism in healthy adults, and it comprised 41 randomized controlled trials (Zhu et al., 2019). Subjective hunger, insulin sensitivity/resistance, caloric intake and expenditure, brain activity changes, hormones that control appetite, changes in weight, and were among the outcomes (Zhu et al., 2019). Sleep restriction was discovered to significantly raise subjective hunger levels in 18 trials, with some proof of a dose-dependent effect (Zhu et al., 2019). Additionally, participants who were subjected to sleep restriction consumed an additional average of 253 kcal per day ($n = 17$) and increased snacks intake ($n = 4$) when compared to the control group (normal sleep) (Zhu et al., 2019a). In 10 trials, there was a significant weight gain (on average 0.34 kg) after sleep restriction (Zhu et al., 2019). During sleep restriction, significant alterations in brain activity ($n = 5$) were detected in response to food stimuli, specifically in areas associated with reward and cognitive control (Zhu et al., 2019). Nevertheless, it was discovered that sleep restriction had no significant effects on mean leptin and ghrelin levels or energy expenditure (Zhu et al., 2019). The findings suggest that sufficient sleep should be a part of recommendations for individuals who are at risk of obesity and associated comorbidities, despite the fact that the authors did point out a number of limitations, primarily related to differences in design of the analyzed studies and their relatively short duration (Zhu et al., 2019).

Additionally, a number of physiological research have demonstrated that insufficient sleep may increase hunger and calorie consumption in people due to changing levels of hormones that control appetite, which is leptin and ghrelin (Schmid et al., 2008; Taheri et al., 2004). Taheri et al. (2004) discovered that shorter sleep

durations (5 hours per night versus 8 hours per night) were related with 15.5% lower levels of leptin and 14.9% higher levels of ghrelin, independent of BMI (Taheri et al., 2004). This finding may suggest that severely short sleep duration could raise appetite, resulting in overconsumption (Taheri et al., 2004)..

According to earlier research, overweight and obese adults are much more prone to experience insomnia or other sleep problems (Pearson et al., 2006). Instead of voluntary sleep curtailment as was previously believed, symptoms of chronic emotional stress or sleep disturbance have been proven to be predictors of insufficient sleep in people with overweight and obesity (Vgontzas et al., 2008). Further research by Vgontzas et al. (2008) revealed that individuals with obesity who did not experience emotional stress or sleep disruptions had sleep duration equivalent to non-obese control subjects (Vgontzas et al., 2008). This may highlight the significance of identifying and treating sleep disorders as a potential therapeutic strategy for obesity (Vgontzas et al., 2008)

Additionally, Dallman et al. (2003) hypothesized that chronic elevation of glucocorticoids, such as cortisol, may contribute to an individual's increased desire for high-fat and high-sugar foods (Dallman et al., 2003). According to their hypothesis, abdominal obesity, stimulus salience, and corticotropin-releasing factor (CRF) activity are all increased when glucocorticoid hormone levels are chronically elevated (Dallman et al., 2003). These effects increase metabolic inhibitory feedback on catecholamine levels in the brain and CRF expression (Dallman et al., 2003).

Overall, current evidence suggests that insufficient sleep is a significant risk factor for both overweight and obesity, acting through behavioural, hormonal, and neurophysiological pathways. At the same time, excess body weight contributes to the development of sleep disturbances, reinforcing a bidirectional relationship. These findings highlight the importance of considering sleep as a key component in strategies aimed at preventing and managing overweight and obesity.

2.4 Potential Explanations for Associations between Sleep, Overweight and Obesity, and Cardiometabolic Health

The mechanisms explaining the connections between inadequate sleep, overweight and obesity, and cardiometabolic health are poorly understood (Gibson-Moore & Chambers, 2019). However, it is well recognized that sleep affects a variety

of physiological processes, such as hormone release, metabolism, and behavioral; as a result, a number of mechanistic processes may be involved (Gibson-Moore & Chambers, 2019). As such, multiple interacting pathways are likely involved in explaining these associations.

Changes in circadian rhythms, which include the sleep-wake cycle, can affect physiological activities essential to metabolic health, such as glucose metabolism (Broussard & Cauter, 2016). Melatonin, commonly known as the "sleep hormone," is a major player in the sleep/wake cycle and aids in synchronizing the secretion of other hormones including cortisol, insulin, and leptin (Gibson-Moore & Chambers, 2019). Melatonin is secreted at night in response to darkness and is inhibited by exposure to light (Gibson-Moore & Chambers, 2019). As a result, changes in melatonin release associated with sleep may result in complications in body homeostasis, such as problems with controlling appetite and metabolic processes (Sun et al., 2018).

Behavioral mechanisms also contribute to the association between short sleep and increased body weight. Individuals who get less sleep might have greater chances throughout the day to take calories, either late at night or early in the morning (Cooper et al., 2018). For instance, there is proof that youngsters often snack whenever they stay awake late to play video games, watch television, or access social media (Cappuccio & Miller, 2017). Restricted sleep has been shown in controlled laboratory experiments to increase daily calorie intake by 250–550 kcal. This could be supported by sleep-related changes in leptin and ghrelin levels (Broussard & Cauter, 2016) and/or a rise in hedonistically (gratification) eating (Cooper et al., 2018a; Demos et al., 2017; Hanlon et al., 2016; Ogilvie & Patel, 2017; St-Onge, 2017). Conversely, the most recent systematic review by Zhu et al. (2019) sometimes does not offer proof for the effects on ghrelin and leptin (Zhu et al., 2019). Lack of sleep also results in exhaustion, which can make it harder to get motivated to cook nutritious meals or to exercise, which increases sedentary behavior (Cooper et al., 2018; Ogilvie & Patel, 2017).

According to epidemiological research, participants with less sleep often choose less nutritious eating choices, such as consuming more calories and fat, less fruits and vegetables, higher amounts, inconsistent meal schedules, and much more regular snacking, especially on foods high in calories (Dashti et al., 2015; St-Onge, 2017). Despite the fact that sleep has a generally minimal effect on dietary outcomes, Dashi et al. (2015) came to the conclusion that over the long run, the overall effect of poor sleep

durations on diet is expected to elevate the prevalence of obesity and its related morbidities (Dashti et al., 2015).

In summary, insufficient sleep contributes to the development of overweight and obesity through a combination of circadian disruption, hormonal imbalance, increased energy intake, and adverse behavioural changes. These mechanisms operate together to promote positive energy balance and metabolic dysregulation, highlighting the importance of adequate sleep in maintaining healthy body weight and preventing progression to overweight and obesity.

2.5 Effects of Different Exercise Modalities on Sleep Quality

Exercise is widely recognized as an effective non-pharmacological strategy to improve sleep quality, particularly among individuals with overweight and obesity, who often experience sleep disturbances such as poor sleep quality and obstructive sleep apnea (Ka et al., 2025). However, different exercise modalities may influence sleep through slightly different physiological and psychological mechanisms.

Aerobic exercise, including walking, cycling, and high-intensity interval training (HIIT), has consistently been associated with improvements in sleep quality. For example, a meta-analysis focusing on obese individuals found that HIIT significantly improved overall sleep quality, including sleep duration, sleep efficiency, and daytime functioning (Kawinchotpaisan et al., 2025a). These benefits are often explained by improvements in cardiovascular fitness, energy expenditure, and regulation of circadian rhythms, which help promote better sleep patterns. More broadly, aerobic exercise has been shown to enhance sleep through mechanisms such as thermoregulation and hormonal balance (H. Wang et al., 2025).

Resistance training also contributes to improved sleep quality, although it may act through different mechanisms. Although fewer studies focus specifically on resistance training in overweight and obese populations, evidence from other clinical groups supports its effectiveness in improving sleep quality and reducing sleep disturbances. For example, a randomized controlled trial by Cunha et al. (2025) demonstrated that 12 weeks of resistance training significantly improved Pittsburgh Sleep Quality Index (PSQI) scores in older adults (Cunha et al., 2025). In addition, physiological studies suggest that resistance training induced muscle damage and subsequent repair processes may increase homeostatic sleep drive, supporting deeper

and more restorative sleep (Ramos-Campo et al., 2020). Resistance training has also been linked to reductions in inflammation and improvements in overall physiological function, which are associated with better sleep outcomes (de Sá Souza et al., 2022).

Combined aerobic and resistance training appears to provide similar benefits. Supporting this, an intervention study in obese adults with sleep-disordered breathing found that a home-based program combining aerobic interval training and resistance training significantly improved subjective sleep disturbances and daytime dysfunction (Longlalerng et al., 2024). These findings suggest that combining modalities may be particularly effective in populations with both obesity and sleep-related disorders. In addition, combined aerobic and resistance programs have been shown to improve body composition, cardiometabolic risk factors, and overall physical function in individuals with overweight and obesity (Al-Mhanna et al., 2024). Similarly, randomized controlled trials in overweight populations report that combined training leads to greater improvements in body mass index and aerobic capacity compared to either aerobic or resistance training alone (Kumari et al., 2025). These improvements are important because metabolic health, body composition, and cardiovascular fitness are closely linked to sleep regulation and sleep quality.

Mind–body exercises, such as yoga and Tai Chi, have also been shown to improve sleep quality, especially in populations experiencing stress or poor mental health. A meta-analysis on Tai Chi interventions demonstrated significant improvements in sleep quality, including reductions in global Pittsburgh Sleep Quality Index (PSQI) scores (Lyu et al., 2024). Similarly, broader reviews indicate that both mind–body and conventional exercises can improve sleep, although mind–body practices may offer additional benefits through stress reduction, relaxation, and improved emotional regulation (H. Wang et al., 2025). These mechanisms are particularly relevant for individuals with overweight and obesity, as psychological factors such as stress and anxiety are closely linked to sleep disturbances.

In summary, current evidence suggests that all major exercise modalities (aerobic, resistance, combined aerobic and resistance, and mind–body exercise) can improve sleep quality in overweight and obese individuals. While combined exercise may provide slightly greater overall benefits, the differences between modalities are generally small. Therefore, the most important factor may be regular participation in exercise rather than the specific type performed.

2.6 Exercise Characteristics and Their Impact on Sleep Quality

Although there is still much to learn about when and how to exercise, several significant results supported the utilization of exercise as a method to enhance sleep quantity and quality over the course of a person's lifetime. It is challenging to compare the results among studies because of changes in the research methodologies, but it is relevant to discuss these variations since they could point to new insights into the connection between exercise and sleep.

These numerous methodological variations were examined in a review by Lang et al., who discovered that participants who engaged in high intensity physical exercise were more likely to have greater sleep quality (Lang et al., 2016). Depending on the time of day the exercise is conducted, Yamanaka et al. (2015) found that daily exercise of moderate intensity had various impacts on circadian melatonin rhythm and rectal temperature during nocturnal sleep, heart rate variability and sleep stages (Yamanaka et al., 2015). The analysis of these findings leads to the conclusion that exercise time affects how well a person sleeps. Since exercise activates the sympathetic nervous system, the authors came to the conclusion that exercising earlier in the day may enhance the quality of nocturnal sleep (Yamanaka et al., 2015). Yamanaka et al. (2015) propose improving parasympathetic activity by giving time to the sympathetic nervous system to slow down in order to improve the quality of sleep (Yamanaka et al., 2015).

In contrast to these results, Alley et al. (2015) discovered that resistance training timing had no significant impact on total or REM sleep the following night (Alley et al., 2015). However, the researchers did come to the conclusion that performing resistance training does enhance sleep quality, irrespective of the time of day (Alley et al., 2015). They also discovered that differences in the timing of resistance training had an impact on sleep-related variables such as wake time after sleep onset (WASO) and sleep onset latency (SOL) (Alley et al., 2015). Specifically, it was discovered that morning exercise greatly reduced the amount of time needed to fall asleep, while evening exercise significantly decreased WASO (Alley et al., 2015).

Alley et al. (2015) findings were confirmed by Brand et al. (2014), who discovered that exercise an hour and a half prior bedtime was linked to greater deep sleep and reduced REM sleep (Brand et al., 2014). To be more precise, people who felt more exerted during exercise had reduced light sleep and greater deep sleep than people who felt less exerted (Brand et al., 2014). The same researchers conclude their results

by claiming that there is a positive relationship between self-perceived exercise exertion and objectively evaluated sleep, indicating that encouraging exercise as part of daily physical activity is probably beneficial to the objective components of sleep (Brand et al., 2014).

Siddarth et al. (2014) conducted research employing two different types of exercise: aerobic exercises in one group and mind-body exercises in the other, such as yoga and Tai Chi. (Siddarth et al., 2014). Meanwhile, S. Du et al. (2015) only utilized Tai Chi as their intervention (S. Du et al., 2017). All of these types of exercise improved sleep quality as determined by PSQI global scores or wrist actigraphy, but Siddarth et al. (2014) discovered that subjects who participated in mind-body exercise had much better moods, mental health, and sleep than those who engaged in aerobic exercise (Siddarth et al., 2014). However, more study needs to replicate to support this claim since it was not profoundly supported. This observation highlights the need for additional research into the physiological mechanisms underlying how exercise and sleep interact. According to Dzierzewski et al. (2014), mood control, anxiety, and arousal are aspects that may have a significant impact on sleep (Dzierzewski et al., 2014). Perhaps, by considering the nature of mind-body exercise, which emphasizes relaxation and the release of stress while simultaneously emphasizing mindfulness of one's emotions and energy through the inclusion of a combination of aerobic and resistance activities at a moderate intensity, this may justify the findings of Siddarth et al. (Siddarth et al., 2014).

2.7 Variations in Exercise Effects on Sleep Quality by BMI Status (Overweight vs Obese)

Sleep disturbances are more prevalent and often more severe in individuals with higher body mass index (BMI), particularly those classified as obese compared to overweight (Patel & Hu, 2008). Epidemiological evidence shows that obesity is strongly associated with poorer sleep quality, shorter sleep duration, and a higher risk of sleep disorders such as insomnia and obstructive sleep apnea (OSA) (Patel & Hu, 2008; Young et al., 2002). This suggests that baseline differences in BMI classification may influence how individuals respond to exercise interventions targeting sleep outcomes.

Exercise has been shown to improve sleep quality in both overweight and obese populations; however, the magnitude and mechanisms of improvement may differ between these groups. In overweight individuals, improvements in sleep are often linked to enhanced mood, reduced anxiety, and better circadian regulation. For example, a randomized controlled trial by King et al. (2008) found that moderate-intensity aerobic exercise significantly improved sleep quality and reduced sleep complaints in sedentary adults, many of whom were overweight (King et al., 1997). These findings suggest that in individuals with less severe metabolic dysfunction, behavioral and psychological mechanisms may play a larger role in sleep improvement.

In contrast, in individuals with obesity, exercise-related improvements in sleep are more strongly associated with physiological and metabolic changes. Obesity is closely linked to systemic inflammation, insulin resistance, and sleep-disordered breathing, all of which negatively affect sleep quality (Tasali & Ip, 2008). Exercise interventions in obese populations have been shown to reduce these risk factors, thereby indirectly improving sleep. For instance, Kline et al. (2011) demonstrated that a structured aerobic exercise program significantly reduced the severity of OSA and improved sleep quality in overweight and obese adults, even in the absence of substantial weight loss (C. E. Kline et al., 2011b). This indicates that exercise can improve sleep through mechanisms beyond simple reductions in body weight.

However, some evidence indicates that improvements in sleep may occur independently of BMI classification. For example, a systematic review by Kredlow et al. (2015) concluded that exercise has a small-to-moderate positive effect on sleep quality across diverse populations, regardless of baseline characteristics such as BMI (Kredlow et al., 2015). This aligns with findings from Yang et al. (2012), who reported consistent improvements in sleep outcomes following exercise interventions in middle-aged and older adults with sleep problems, without identifying BMI as a significant moderator (Yang et al., 2012).

In summary, while exercise improves sleep quality in both overweight and obese individuals, the underlying mechanisms and magnitude of effects may differ. In overweight populations, improvements are more likely driven by psychological and behavioural factors, whereas in obese individuals, physiological and metabolic changes play a more prominent role. Nevertheless, current evidence suggests that exercise remains an effective strategy for improving sleep quality across BMI classifications, even if the pathways of improvement differ.

2.8 Differential Effects of Exercise on Sleep Quality Based on Sleep Status

The impact of exercise on sleep quality may differ depending on baseline sleep condition, particularly between individuals with normal sleep and those with sleep disorders. Sleep disturbances are highly prevalent in overweight and obese populations, with conditions such as insomnia and obstructive sleep apnea (OSA) occurring more frequently as body mass index (BMI) increases (Peppard et al., 2013; Young et al., 2002). These baseline differences are important because individuals with existing sleep problems often have greater potential for improvement following exercise interventions.

In individuals with sleep disorders, exercise has consistently been shown to produce meaningful improvements in both subjective and objective sleep outcomes. For example, a randomized controlled trial by Reid et al. (2010) demonstrated that a 16-week aerobic exercise program significantly improved sleep quality, sleep latency, and sleep duration in older adults with chronic insomnia (Reid et al., 2010). Similarly, in overweight and obese individuals with OSA, Kline et al. (2011) found that moderate-intensity aerobic exercise significantly reduced apnea–hypopnea index (AHI) and improved overall sleep quality, even without substantial weight loss (C. E. Kline et al., 2011a). These findings suggest that exercise can directly improve sleep by reducing the severity of underlying sleep disorders, possibly through mechanisms such as improved cardiorespiratory fitness and reduced fluid shift to the upper airway during sleep.

Exercise may also improve sleep in individuals with insomnia by targeting psychological and physiological mechanisms. Regular physical activity has been shown to reduce hyperarousal, anxiety, and depressive symptoms, all of which are key contributors to insomnia (Passos et al., 2011). A clinical trial by Passos et al. (2011) reported that moderate aerobic exercise significantly reduced insomnia severity and improved sleep efficiency in patients with chronic primary insomnia (Passos et al., 2011). These improvements are particularly relevant for overweight and obese individuals, who often experience elevated psychological stress and mood disturbances that negatively affect sleep.

In contrast, the effects of exercise on sleep among individuals without diagnosed sleep disorders (normal sleepers) tend to be smaller. A meta-analysis by Kredlow et al. (2015) found that while exercise improves sleep overall, the magnitude of effect is generally modest in healthy individuals without significant sleep complaints (Kredlow et al., 2015). Similarly, Youngstedt et al. (1997) reported that acute exercise had

minimal impact on sleep architecture in good sleepers, suggesting that there may be a ceiling effect when baseline sleep quality is already adequate (Youngstedt et al., 1997). This may explain why some intervention studies in general populations report only small or non-significant improvements in sleep outcomes following exercise.

Importantly, individuals with overweight and obesity who also have poor baseline sleep may experience greater benefits from exercise due to their higher initial level of impairment. Dzierzewski et al. (2014) found that physical activity was more strongly associated with improved sleep in individuals with poorer baseline sleep quality (Dzierzewski et al., 2014). This suggests that baseline sleep condition acts as a moderator, where those with worse sleep derive greater benefit from exercise interventions.

In summary, the effectiveness of exercise on sleep quality appears to depend on baseline sleep condition. In overweight and obese individuals with sleep disorders such as insomnia or OSA, exercise produces more substantial improvements by addressing both physiological and psychological contributors to poor sleep. In contrast, among normal sleepers, the effects of exercise are generally smaller, likely due to already adequate sleep quality. These findings highlight the importance of considering baseline sleep status when evaluating the impact of exercise interventions on sleep outcomes.

2.9 Subjective and Objective Sleep Quality Assessments

Both objective and subjective measures can be used to evaluate the quality of sleep. In order to acquire data on sleep variables, objective methodologies approach with high reliability include actigraphy and polysomnography (PSG) (Krystal & Edinger, 2008). However, many healthcare professionals do not have easy access to these objective approaches in everyday practice, and they are also costly and time-consuming as well (American Academy of Sleep Medicine, 2005). There is still another method for assessing sleep quality which is subjective methodologies. Many researchers decided to choose subjective assessments since it is easier and inexpensive.

2.9.1 Subjective Assessments

2.9.1.1 Pittsburgh Sleep Quality Inventory (PSQI)

There are two primary factors that make the Pittsburgh Sleep Quality Inventory (PSQI) the most widely used subjective self-report sleep quality assessment (Buysse et

al., 1989). The PSQI was created to measure sleep quality, but it additionally serves as convergent validity in a significant number of research studies that validate sleep questionnaires, indicating that it can be regarded as the professional standard or reference for self-perceived sleep quality (Buysse et al., 1989). Additionally, it is the most popular measure for assessing sleep health in both clinical and non-clinical groups (Mollayeva et al., 2016). In the current review, this questionnaire had the most research studies examining its psychometric features outside of factor structure (Fabbri et al., 2021). The PSQI was made up of 24 questions or rating items that related to the previous month (0–3, for 20 items, while 4 were open-ended) (Fabbri et al., 2021). Of these, 19 items were self-reported, whereas 5 items required second-hand assessment from a friend or roommate (Fabbri et al., 2021). For the examination of the individuals' perceptions of their sleep quality, only 19 items (15 rated 0–3 and 4 open-ended) were employed (Fabbri et al., 2021). According to the range of values stated by the patients, the open-ended questions were also assessed as categorical values (rated 0-3) (Fabbri et al., 2021). The PSQI's seven components—sleep quality (C1), sleep latency (C2), sleep duration (C3), habitual sleep efficiency (C4), sleep disturbance (C5), use of sleep medications (C6), and daytime disturbance (C7) were then represented by scores ranging from 0 (no difficulty) to 3 (severe difficulty) based on these 19 self-reported questions (Fabbri et al., 2021). The results were added up to provide a final score, also known as the global score (range 0–21), which served as an effective assessment of the participant's sleep pattern and quality (Fabbri et al., 2021). Refer Appendix B for the scoring of the global score. In summary from a review by Fabbri, in particular for known-group validity, PSQI showed strong reliability and validity (Fabbri et al., 2021). However, the lengthy recall interval, and the scoring methodology put into question the efficacy of the overall PSQI score in identifying poor and good sleepers (Fabbri et al., 2021).

2.9.1.2 Sleep diary

The most frequently used evaluation tool amongst the subjective measures is the sleep diary (Natale et al., 2015). The individual has to fill out daily morning estimations for the variables regarding their sleep schedule in the sleep diary (Natale et al., 2015). As a result, data regarding a variety of essential indicators, which includes SOL, WASO, TST, total time in bed (TIB), SE, and satisfaction as a subjective overall rating for every night's sleep is obtained (Natale et al., 2015). However, it is noticeable that its effective

utilization depends significantly on daily (prospective) data made as soon as the individuals wake up in the morning, which is something that may be challenging for the elderly to maintain a routine continually, restricting the usefulness of the sleep diary for evaluation or epidemiological research (Fabbri et al., 2021). Retrospective self-report assessments, especially questionnaires, on the other hand, can be broadly implemented in both routine care and clinical studies due to a number of benefits, such as being inexpensive and having the ability to be given to a variety of populations over the Internet (Thorndike et al., 2011). Additionally, these assessments are self-explanatory and will not require supervision, so they can be used in both settings (Thorndike et al., 2011). Self-rating assessments also have the benefits of excellent adherence among patients, simplicity in administration, and a lower time demand on the part of medical professionals (Fabbri et al., 2021).

2.9.1.3 Insomnia Severity Index (ISI)

The Insomnia Severity Index (ISI), which assesses perceived insomnia severity, is identical to the AIS and focuses on the degree of sleep pattern disruption, the effects of insomnia, and the level of concern and distress associated with the sleep issue (Bastien et al., 2001). The ISI consists of seven criteria that evaluate the degree of sleep-onset and sleep maintenance problems (both nighttime and early morning awakening), satisfaction with the present sleep routine, disturbance with normal daily activities, noticeability of limitation due to the sleep issue, and level of emotional distress or anxiety resulted by the sleep difficulties (Fabbri et al., 2021). The time interval is "in the previous 2 weeks," and each of the following items is scored on a five-point Likert scale (0 = not at all; 4 = extremely) (Fabbri et al., 2021). Total scores may differ from 0 to 28, as higher numbers indicate more severe insomnia (Fabbri et al., 2021).

2.9.2 Objective Assessments

2.9.2.1 Polysomnography (PSG)

SOL, TST, WASO, awakenings, the quantity and percentage of the various sleep stages (stages 1, 2, slow wave sleep [SWS], and REM), REM latency, the frequency of apneas and hypopneas, and periodic motions of sleep are among the objective sleep indicators produced by PSG (Wolpert, 1969). In combination, these variables offer measures of: (1) the duration and volume of sleep; (2) the frequency of pathological

incidents indicating of periodic limb movement disorder, also known as PLMD, and sleep disordered breathing (SDB); and (3) the length and relative distribution of every sleep stage (Krystal & Edinger, 2008). Measures of sleep duration and quality have been found helpful in a variety of situations, including measuring outcomes in studies evaluating treatments for insomnia (Krystal & Edinger, 2008). For the diagnosis and therapy of these diseases, the PSG-derived markers of SDB and PLMD have been the gold standard and reference for many healthcare professionals (Krystal et al., 2008). The quantity and distribution of traditionally graded sleep stages are the only variables that accurately indicate the kind and quality of sleep (Krystal & Edinger, 2008). Traditional sleep stage scoring, on the other hand, is a poor indicator because it only offers the following four possibilities for describing the stage of sleep: stage 1, stage 2, SWS, or REM (Krystal & Edinger, 2008). Furthermore, this stage depiction is an artificial division of a continuous process (Krystal & Edinger, 2008). According to Krystal et al. (2008), sleep stages offer an inadequate description of the nature and depth of sleep may contribute to the finding that only 50–60% of subjects who comply with the criteria for insomnia diagnosis have PSG-derived indicators that are different from those of normal sleepers, despite the fact that data reduction is essential in order to analyze the enormous quantity of data obtained during PSG (Krystal & Edinger, 2008). Traditional PSG values may not be accurate and thorough indicators of "sleep quality" since "sleep quality" might represent other components of sleep, timing, basic stage structure, and the incidence of pathologic occurrences (Krystal & Edinger, 2008).

2.9.2.2 Actigraphy

Actigraphy includes the use of a device that is often worn on the wrist and monitors motion as a substitute for wakefulness (Acebo & LeBourgeois, 2006). Actigraphy's main benefit is that it is inexpensive and reasonably user-friendly, enabling data to be recorded over lengthy periods of time (Krystal & Edinger, 2008). The main drawback of this approach is that movement is only a substitute for sleep and not sleep itself, making it difficult to differentiate between being still when awake and being asleep (Krystal & Edinger, 2008). For instance, longer nighttime awakenings and delayed initiation of sleep, which are considered to be the main symptoms of insomnia, cause patients to experience longer periods of peaceful wakefulness, which actigraphy is likely to record as sleep instead of awake (Acebo & LeBourgeois, 2006). Another drawback is the lack of comparisons between the various devices and grading

algorithms that are currently available (Krystal & Edinger, 2008). Total sleep time is the most accurate and verified indicator of sleep, and the ideal actigraphy usage is to represent the pattern of the sleep/wake cycle over a period of many days (Krystal & Edinger, 2008). Actigraphy is best viewed as an indicator of amount of sleep or duration instead of as a measurement of the quality or depth of sleep, considering that the most verified index is total sleep time (Krystal & Edinger, 2008). In this context, five studies found that, in placebo-controlled experiments, the use of insomnia treatments caused changes in actigraphy measurements of sleep duration or timing (Krystal & Edinger, 2008a).

CHAPTER 3

METHODOLOGY

3.1 Research Conceptual Framework

Figure 3.1 shown the research conceptual framework of the research project. The types of exercises (aerobic, resistance, aerobic + resistance, and mind-body exercise) were the independent variables while the effect of exercise on sleep quality were the dependent variable.

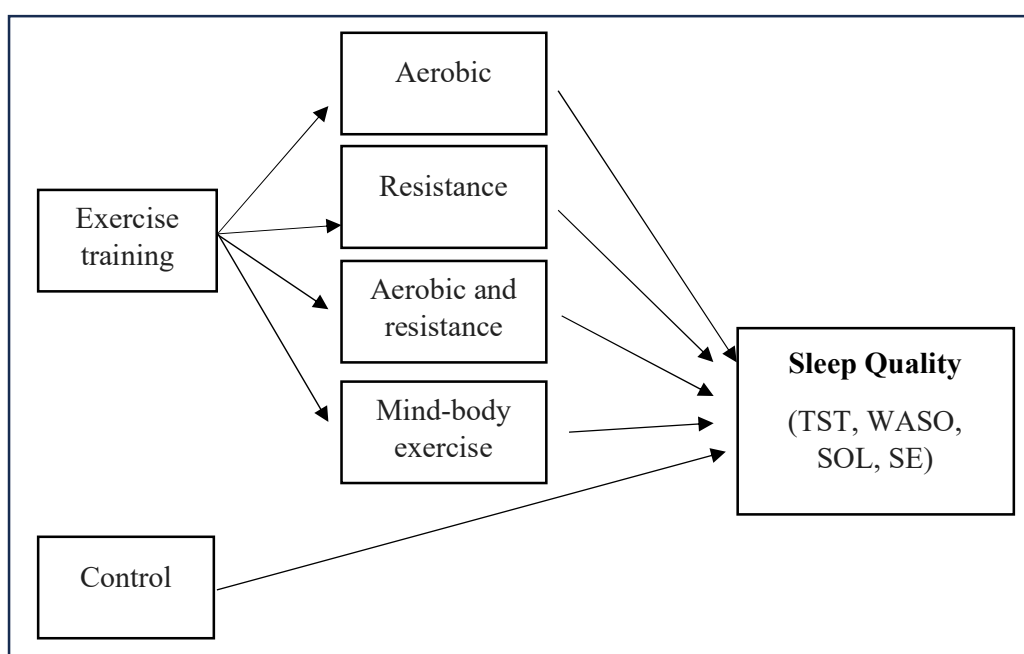


Figure 3.1 Research Conceptual Framework

It is clear from the literature review that exercise may have potential effect on the sleep quality. Therefore, this study hypothesized that the meta-analysis demonstrates a significant effect of exercise on the sleep quality in overweight and obese.

3.2 Search Strategy

The reporting of this analysis were guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Page et al., 2021), and it was registered in the International Prospective Register of Systematic Reviews

(PROSPERO ID number: CRD42024576949). The following electronic databases were used in the search: PubMed, ScienceDirect, Web of Science and Cochrane Library. All relevant articles published from these databases were searched up to May 2025.

This study utilized a variety of search strategies to ensure that all relevant articles are included for accurate result analysis. Firstly, all authors decided on keywords, from which the search term were generated. The list of synonyms were searched to broaden the search term. Additionally, Boolean searching was performed by combining keywords with operator words like AND, OR, and NOT. Boolean searching was used to help search engines in limiting or expanding the search results. Keywords or forms of keywords used in the database searches included exercise, physical fitness, systematic review, meta-analysis, sleep quality, sleep quantity, overweight and obese. The list of the search strategies used for each database is shown in Table 3.1. Moreover, the authors referred previous systematic reviews and meta-analysis to locate related articles. Furthermore, a manual search of the references from the included studies was also conducted to avoid missing literature. Besides that, the author applied the inter-library loan at UiTM Library website (<https://ptarapps.uitm.edu.my/login/>) for articles that have no access to full text, which only provide the abstract of the study.

Two of the authors (NFS & NFI) independently performed the electronic search on the databases using the keywords. Retrieved articles were screened and any duplicate articles were removed. In the event of a disagreement, the third author (HI) has been consulted, and the issue has been resolved by agreement among all three authors.

Table 3.1

Search Strategy Method

No.	Search method	Combination terms
1.	Online database: PubMed, Web of Science, Cochrane and ScienceDirect	#1 “exercise” OR “physical exercise” OR “aerobic exercise” OR “aerobic training” OR “resistance exercise” OR “resistance training” OR “mind-body exercise” OR “yoga” OR “Pilates” OR “Tai Chi” #2 “sleep quality” OR “sleep quantity” OR “sleep disorder” OR “sleep disturbances” #3 “overweight” OR “obese” #4 search #1 AND #2 #5 search #2 AND #3 #6 search #1 AND #3 #7 search #1 AND #2 AND #3
2.	Previous Related SR and MA	Cross check previous related systematic review and meta-analysis
3.	Reference list	Cross check reference list in the selected article
4.	Interlibrary loan	UiTM library
5.	Author	

SR = Systematic Review; MA = Meta-analysis

3.3 Eligibility Criteria

The **PICOS** (Population, Intervention, Comparison, Outcomes, Study Design) framework (Tacconelli, 2010) was used to operationalize the eligibility criteria of the studies to be included in this analysis.

3.3.1 Types of Population

The study participants were adults classified as overweight or obese. In accordance with World Health Organization (WHO) guidelines, a BMI of 25.0–29.9 kg/m² was considered to be overweight, and a BMI of ≥ 30.0 kg/m² was considered obese (World Health Organization, 2025). Studies involving overweight and obese individuals with common comorbidities, especially sleep disorders consisting of insomnia, obstructive sleep apnea (OSA), and restless legs syndrome, were included as well in order to increase the findings' applicability. Other conditions commonly linked to obesity, such as type 2 diabetes, and hypertension, were also considered accepted. Comorbidities were not restricted unless they specifically hindered safe engagement in exercise interventions.

Individuals with overweight and obesity frequently present with comorbid conditions such as sleep disorders, type 2 diabetes, and metabolic syndrome, which are

intrinsically linked to both impaired sleep quality and altered physiological responses to exercise. Excluding these populations would limit the external validity and clinical applicability of the findings, as it would not reflect real-world populations in which multimorbidity is common. Furthermore, sleep disturbances in obesity are often mediated or exacerbated by such comorbidities, particularly conditions like insomnia and obstructive sleep apnea, making their inclusion essential for a comprehensive evaluation of sleep outcomes. Therefore, studies involving participants with obesity-related comorbidities were included to better capture the complexity of this population and to enhance the generalizability of the results. The potential confounding effects of comorbidities will be addressed through subgroup analyses.

3.3.2 Types of Intervention

The interventions included any form of exercise program. The American College of Sports Medicine guidelines defined exercise as "planned, organized, and continuous movement of the body intended to enhance and/or maintain one or more components of physical fitness." (Riebe et al., 2020). Eligible exercise modalities encompassed aerobic training (e.g., walking, jogging, cycling, swimming), resistance training, mind–body exercise such as yoga, tai chi, or Pilates, in addition to multimodal or combined exercise regimens. Both supervised and unsupervised interventions were considered acceptable, understanding the various modalities through which exercise programs are carried out in clinical and community settings (facility-based and home-based). No restrictions were placed on exercise intensity, frequency, duration, or overall volume, enabling the incorporation of interventions from light-intensity exercise to structured high-intensity training programs.

3.3.3 Types of Comparison

The comparison groups were made up of participants who did not take part in any structured exercise program. Participants in the comparison groups did not take part in any organized exercise programs. This comprised control groups that continued with their regular daily routines without the need for extra exercise, as well as groups that were receiving usual care, sleep hygiene, simple stretching or attending health education classes. Usual care was defined as the continuation of participants' current lifestyle or medical treatment practices (Thompson & Schoenfeld, 2007), whereas health education programs usually included advice on disease prevention, nutrition, and

general wellness without a scheduled exercise component (King et al., 2008). Sleep hygiene, which was first created to treat mild to severe insomnia, is a collection of environmental and behavioural guidelines meant to encourage healthy sleep (Hauri, 1977). Moreover, the definition of stretching is "the utilization of force to musculotendinous tissues with the objective to accomplish an increase in their length, commonly for the objective of enhancing joint range of motion (ROM), decreasing stiffness or discomfort, or preparing for (physical) activity" (Armiger & Martyn, 2010). Studies without a control group, or those that compared exercise interventions only against another exercise-based intervention, were excluded from the analysis.

3.3.4 Outcomes Measure

The primary outcome of this study was the assessment of both subjective and objective sleep quality after exercise intervention. Subjective sleep quality emphasizes the psychological components of sleep, based on each individual's assessment of their sleep session and overall restfulness and it is frequently assessed using measures like the Pittsburgh Sleep Quality Index (PSQI) (Refer Appendix A). The PSQI analyses sleep quality throughout the past month. It delivers a global score ranging from 0 to 21, with a score of 5 or more reflecting poor quality of sleep. In the meantime, objective sleep quality concentrates on quantifiable physiological characteristics of sleep using technologies like Actigraphy or Polysomnography (PSG). TST, WASO, SE, and SOL were the main variables that were obtained through these objective measures. A study was considered eligible for inclusion if it reported at least one relevant outcome variable.

3.3.5 Types of Study Design

Only RCTs (randomized controlled trials) were considered in the review. Studies that particularly examined on how exercise interventions affected the quality of sleep for individuals who were overweight or obese were eligible. To maintain methodological integrity and reduce potential bias in calculating the effects of exercise on sleep outcomes, studies using non-randomized, quasi-experimental, observational, or cross-sectional designs were disqualified. Language was restricted to English exclusively. No limits on the year of publishing and country were implemented.

3.4 Study Selection

Study selection followed the PRISMA guidelines and was carried out in three stages. The first stage was identification, in which all potentially relevant articles retrieved from the four selected online databases were compiled into a single folder, and duplicate records were removed. The second stage was screening, where the remaining articles were assessed based on their titles and abstracts. At this stage, articles were excluded if they did not meet the predefined inclusion criteria. The third stage involved a full-text review, which was conducted independently by two researchers (NFS & NFI) using a standardized form to ensure consistency and to minimize the risk of bias across the screening process. Following this, the reports were assessed for eligibility. Articles with incomplete or insufficient data, were attempted to contact the corresponding authors or to obtain the full text through the Universiti Teknologi MARA (UiTM) interlibrary loan service, for the final selection. Any disagreements between the two reviewers (NFS & NFI) at any stage of the process were resolved through discussion and, when necessary, consultation with a third reviewer (HI). Refer Figure 4.1.

3.5 Data Extraction

The data extracted from each included study encompassed several key domains to ensure comprehensive synthesis and analysis. These domains included: (1) study identification details, such as the first author's name and year of publication; (2) participant characteristics, including clinical profiles, age, and the sample size allocated to each group (intervention and control); (3) intervention specifics, which detailed the type of exercise employed, the frequency of exercise sessions per week, the duration of each session (in minutes), the prescribed intensity of the exercise, the total duration of the intervention period (in weeks or months), and the level of adherence reported by participants; (4) the nature of the control interventions used for comparison (e.g., wait-list control, usual care, or alternative treatments); and (5) sleep-related outcomes assessed, categorized by measurement type (subjective measures, or objective measures).

To ensure accuracy and consistency in data extraction, any discrepancies or disagreements that arose between the primary reviewers were addressed through thorough discussion. If consensus could not be reached through initial dialogue, the

issue was escalated and resolved by consulting a third reviewer (HI), thereby ensuring a balanced and unbiased resolution process.

3.6 Quality Assessment

The methodological quality of the included studies will be evaluated using the Tool for the Assessment of Study Quality and Reporting in Exercise (TESTEX), a validated instrument specifically developed by Smart et al. (2015) for use in exercise training research (Smart et al., 2015).

The TESTEX tool provides a comprehensive and exercise-specific approach for evaluating methodological rigor and reporting standards, helping to strengthen the reliability and interpretability of conclusions drawn from exercise intervention studies. Unlike more general appraisal tools, TESTEX incorporates criteria that are particularly relevant to exercise-based interventions, such as exercise adherence, monitoring of training intensity, and reporting of exercise volume. These features make it especially suitable for the present meta-analysis, which focuses on exercise-related outcomes. Furthermore, TESTEX has been increasingly adopted in systematic reviews and meta-analyses within exercise science and related health fields (Hernandez-Martinez et al., 2024; Pinho et al., 2024; X. Wang et al., 2025), reflecting its growing recognition as a rigorous and context-specific quality assessment instrument. A higher total TESTEX score is indicative of superior methodological and reporting quality, while lower scores may reflect greater risk of bias or incomplete reporting.

The TESTEX scale provides a structured framework consisting of a maximum score of 15 points, divided into two key domains: 5 points allocated for assessing study quality, and 10 points for evaluating reporting quality. The study quality domain includes the following criteria, each contributing one point: (1) specification of eligibility criteria for participant inclusion, (2) implementation of a randomization procedure, (3) use of allocation concealment, (4) baseline comparability between intervention and control groups, and (5) blinding of outcome assessors to group assignments.

The reporting quality domain includes ten criteria, each also worth one point, which assess the comprehensiveness and transparency of the study's reporting. These criteria are: (1) participant adherence to the exercise intervention exceeds 85%, (2) documentation of any adverse events, (3) detailed reporting of exercise session

attendance, (4) use of intention-to-treat analysis, (5) reporting of between-group statistical comparisons for the primary outcome, (6) reporting of between-group comparisons for at least one secondary outcome, (7) presentation of point estimates and measures of variability (e.g., standard deviation, confidence intervals) for all reported outcomes, (8) monitoring of physical activity levels in the control group, (9) reporting of relative exercise intensity, and (10) clear documentation of exercise volume and energy expenditure. Refer Appendix C for scoring of TESTEX.

3.7 Statistical Analysis

The pre–post changes, or mean differences, were calculated utilizing a random-effects model (REM) in RevMan 5.4. The cumulative mean summary effect was additionally assessed utilizing REM. This model was selected because to its consideration of variability among studies regarding participant characteristics, intervention forms, outcome measures, and study methods. In summary, REM was especially appropriate for analyses anticipating heterogeneity (Pathak et al., 2020). The current analysis included research using various exercise protocols and designs, making the use of REM both suitable and essential.

Since systematic reviews offer the greatest level of evidence for evaluating the advantages and risks of medical therapies, detecting and reporting publication bias in systematic reviews and meta-analyses is critical. Failure to address this issue could result in skewed results, as a significant degree of publication bias might jeopardize the reliability of the findings and prevent them from accurately reflecting the real objectives of the study. Publication bias was evaluated by a funnel plot, which illustrates research effect sizes in relation to their standard errors. Publication bias has been extensively assessed by funnel plot asymmetry (Light & Pillemer, 1984). The funnel plot acts as a visual tool to evaluate bias by plotting research effect sizes against their standard errors. The funnel plot is a visual estimating approach that analyses whether studies are spread symmetrically on both sides of the plot. When an approximately equal number of papers appear on the left and right sides, the plot is considered symmetrical, demonstrating that no publication bias exists (Tawfik et al., 2019).

When publication bias is detected, researchers have to assess the extent of bias and the degree of heterogeneity. In this study, heterogeneity was examined using the I^2 statistic. A high I^2 score implies strong heterogeneity, indicating that the variation in

results is caused more by actual differences between studies than by randomness. Thus, results should be regarded with caution. Conventionally, an I^2 of 25% is regarded low, 50% moderate, and 75% high (L. Du et al., 2021). An I^2 score of 75% implies high discrepancy among study findings (Vromen et al., 2016). In cases of high heterogeneity, potential sources should be identified, and subgroup analysis can potentially be performed (Pathak et al., 2020). Conversely, when heterogeneity is small, results may be perceived as closely matched with the study's objectives.

The standardized mean difference (SMD) and 95% confidence interval (CI) were employed for reporting changes in the outcome measures. The criterion for statistical significance was fixed at $p < 0.05$. Figures were generated using the Revman 5.4.

CHAPTER 4

RESULT

4.1 Search Result

Figure 4.1 outlines the results of the literature search and screening process. A total of 1377 articles were identified through computerized searches. After removing duplicates, 1049 articles remained. Of these, 876 were excluded for not meeting the predefined inclusion criteria. Retrieval was attempted for 173 articles, but 21 could not be obtained. A thorough review of 152 full-text articles for eligibility resulted in the exclusion of 127, primarily due to reasons such as not involving overweight or obese participants, or having an inappropriate control group. Ultimately, 25 full-text articles, comprising a total of 2338 participants, were included in the qualitative synthesis and meta-analysis. All included articles were published in English.

4.2 Study Characteristics

The meta-analysis included 32 randomized controlled trials (RCTs). In five studies (Buchanan et al., 2017; Ebrahimi et al., 2017; Jurado-Fasoli et al., 2020; Leonel et al., 2022; Quist et al., 2019), interventions with multiple exercise groups were treated as separate studies, each focusing on a distinct exercise intervention. Table 4.1 provides comprehensive details on participant characteristics, exercise and control group interventions, sleep assessment, and results. All studies were published between 2006 and 2023.

Of the 32 RCTs included in Table 4.1, 13 studies involved healthy participants with no comorbidities other than being overweight or obese. The remaining 19 RCTs included participants with conditions such as Type 1 diabetes mellitus (T1DM), Type 2 diabetes, primary hypertension, non-alcoholic fatty liver disease (NAFLD), sleep disorders, menopausal women experiencing hot flashes, breast cancer survivors, depressive symptoms, restless legs syndrome, and frequent vasomotor symptoms (VMS). Sample sizes ranged from 7 to 162 participants per group.

The exercise interventions varied, including aerobic, resistance, combined aerobic and resistance, yoga, Pilates and Tai Chi. The programs lasted between 6 and 48 weeks, with session frequencies ranging from 1 to 6 times per week and durations of 20 to 120 minutes per session. Exercise intensity ranged from low to vigorous.

24 RCTs assessed subjective sleep quality, while 12 RCTs measured objective sleep quality.

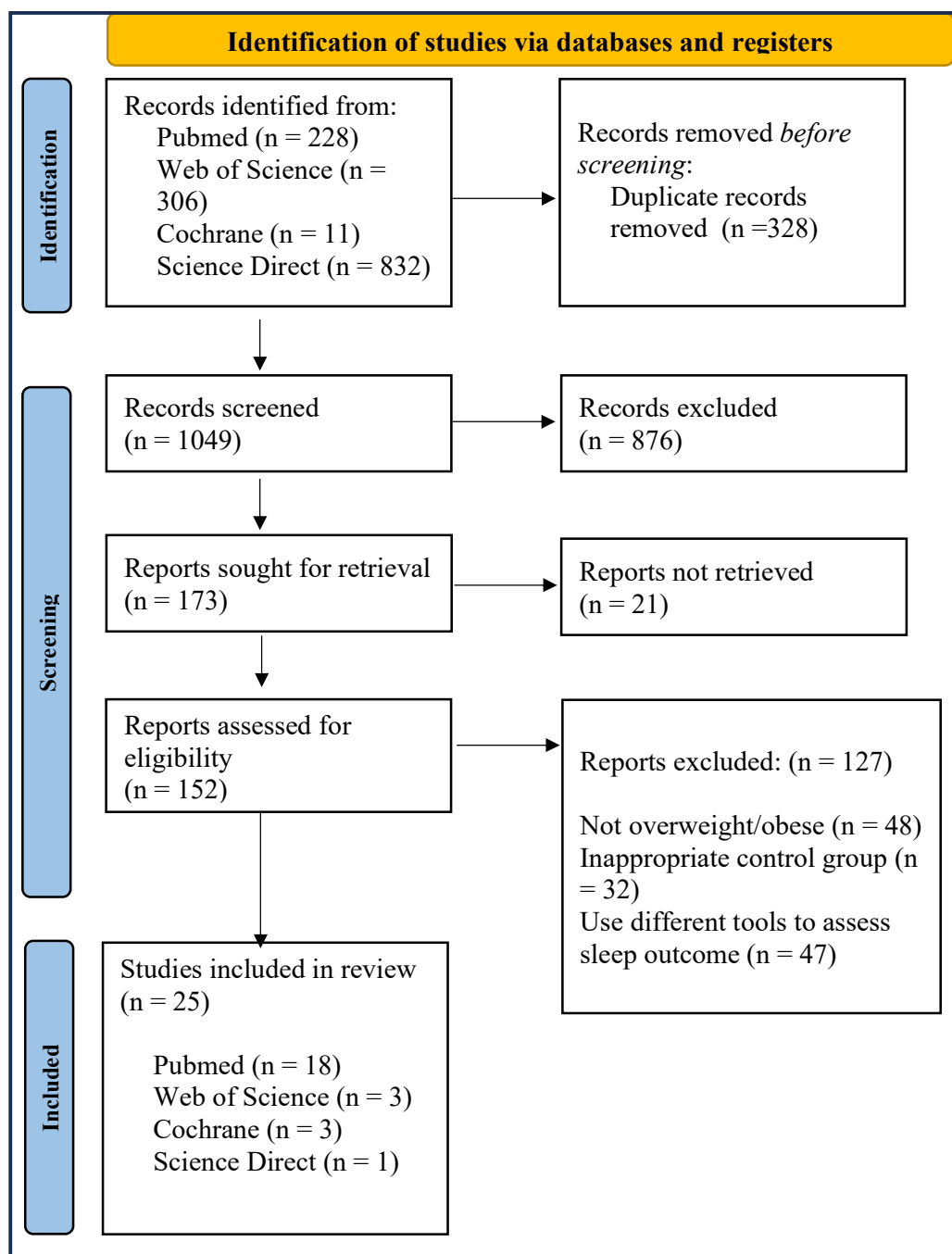


Figure 4.1 Flowchart representing summary of the study selection process

Table 4.1

Characteristics of the included studies and participants

Author, year	Clinical Condition	Sample size	Age	Exercise Intervention	Control Intervention	Sleep Outcomes/ Device	Main results for exercise intervention
Abd El- Kader et al., 2020	Chronic primary insomnia	IG: 40 CG: 40	35-56 years old	Type: Aerobic Duration: 24 weeks Frequency: 3 days/week Intensity: 60 – 70% HRmax Time: 45 min/session Adherence: Not reported	Usual care	PSG	All PSG outcomes significantly improved ($p < 0.05$)
Aguirre- Betolaza et al., 2020	Primary hypertension	IG: 162 CG: 56	Not reported	Type: Aerobic Duration: 16 weeks Frequency: 2 days/week Intensity: 65 – 90%VO ₂ peak Time: 60 min/session Adherence: Not reported	Usual care	Accelerometer	SE improved by 4.4%
Aibar- Almazán et al., 2019	None	IG: 55 CG: 52	60 years old and above	Type: Pilates Duration: 12 weeks Frequency: 2 days/week Intensity: – Time: 60 min/session Adherence: 91.6%	Usual care	PSQI	Significant improvements were noted on sleep duration ($p = 0.0010$) and sleep disturbances ($p < 0.001$) components
Alarcon- Gomez et al., 2021	Type 1 Diabetes Miletus	IG: 11 CG: 8	18-45 years old	Type: Aerobic Duration: 6 weeks Frequency: 3 days/week	Usual care	PSQI	Sleep quality improved by 21.4%

				Intensity: 50 – 75% HRR Time: Not reported Adherence: Not reported			
Atlantis et al., 2006	None	IG: 20 CG: 24	Middle age (did not specify range)	Type: Combined aerobic and resistance training Duration: 24 weeks Frequency: 3 days/week Intensity: 50 – $\geq$ 75% HRmax & 15 reps of 1RM Time: 60 min/session Adherence: 60%	Usual care	PSQI	Sleep quality improved ($p = 0.006$)
Brandão et al., 2018	None	IG: 61 CG: 64	60 years old and above	Type: Combined aerobic and resistance training + balance + stretching + sleep hygiene Duration: 12 weeks Frequency: 3 days/week Intensity: 13 – 15 RPE Time: 40 min/session Adherence:	Sleep hygiene	PSQI	Sleep quality improved ($p < 0.01$)
Buchanan et al., 2017 (a)	Menopausal women with hot flashes	IG: 52 CG: 80	45 years old and above	Type: Yoga Duration: 12 weeks Frequency: 3 days/week Intensity: – Time: 90 min/session Adherence: 60%	Usual care	Actigraphy	No significant effects on all actigraphy outcomes
Buchanan et al., 2017 (b)	Menopausal women with hot flashes	IG: 54 CG: 80	45 years old and above	Type: Aerobic Duration: 12 weeks Frequency: 1 day/week Intensity: 50 – 70% HRR	Usual care	Actigraphy	No significant effects on actigraphy outcomes

				Time: 40 – 60 min/session Adherence: 83%			
Dieli-Conwright et al., 2021	Breast cancer survivors	IG: 46 CG: 45	Mean age: 52	Type: Combined aerobic and resistance training Duration: 16 weeks Frequency: 3 days/week Intensity: 60 – 80% 1RM, 65 – 80% HRmax Time: 50 – 80 min/session Adherence: 96%	Usual care	PSQI	Sleep quality improved by 40%
Drew et al., 2021	Men with depressive symptoms	IG: 62 CG: 63	18-70 years old	Type: Resistance Duration: 12 weeks Frequency: Not reported Intensity: Not reported Time: Not reported Adherence: Not reported	Usual care	PSQI	No significant effects were observed ($p = 0.06$)
Duncan et al., 2020	None	IG: 80 CG: 36	19-65 years old	Type: Resistance Duration: 24 weeks Frequency: Not reported Intensity: Not reported Time: Not reported Adherence: 83%	Usual care	PSQI	Sleep quality did not improve ($p > 0.05$)
Ebrahimi et al., 2017 (a)	Type 2 Diabetes	IG: 13 CG: 15	38-53 years old	Type: Aerobic Duration: 12 weeks Frequency: 3 days/week Intensity: 60 – 75% HRRmax Time: 35 – 45 min/session Adherence: Not reported	Usual care	PSQI	Significant effect was observed after 6 weeks of aerobic exercise ($p = 0.039$),

							however insignificant after 12 weeks ($p = 0.154$)
Ebrahimi et al., 2017 (b)	Type 2 Diabetes	IG: 15 CG: 15	38-53 years old	Type: Yoga Duration: 12 weeks Frequency: 3 days/week Intensity: – Time: 90 min/session Adherence: Not reported	Usual care	PSQI	Sleep quality improved after six ($p = 0.001$) and 12 ($p = 0.001$) weeks of yoga exercise
Ezpeleta et al., 2023	Non-alcoholic fatty liver disease	IG: 15 CG: 20	18 – 65 years old	Type: Aerobic Duration: 12 weeks Frequency: 5 days/week Intensity: 65 – 85% HRmax Time: 60 min/session Adherence: Not reported	Usual care	PSQI	Sleep quality did not improve
Innes et al., 2012	Older women with restless legs syndrome	IG: 10 CG: 10	45-79 years old	Type: Yoga Duration: 8 weeks Frequency: 2 days/week Intensity: – Time: 90 min/session Adherence: 81.25%	Educational film	PSQI	Sleep quality improved ($p \leq 0.05$)
Irwin et al., 2014	Insomnia	IG: 48 CG: 25	55 years old and above	Type: Tai Chi Duration: 16 weeks Frequency: 1 day/week Intensity: – Time: 120 min/session Adherence: 74%	Sleep seminar	PSQI PSG	PSQI global score improved ($p < 0.05$) but PSG outcomes were not significant ($p > 0.05$)

Jurado-Fasoli et al., 2020 (a)	None	IG: 17 CG: 15	45-65 years old	Type: Combined aerobic and resistance training Duration: 12 weeks Frequency: 3 days/week Intensity: 60 - 65% HRR, 40 -50% 1RM Time: 70 min/session Adherence: 98.7%	Usual care	PSQI	Improved sleep quality ($p < 0.05$)
Jurado-Fasoli et al., 2020 (b)	None	IG: 18 CG: 15	45-65 years old	Type: Aerobic Duration: 12 weeks Frequency: 2 days/week Intensity: >95 - 120% VO ₂ max Time: 20 – 35min/session Adherence: 98.7%	Usual care	PSQI	Improved sleep quality ($p < 0.01$)
Jurado-Fasoli et al., 2020 (c)	None	IG: 19 CG: 15	45-65 years old	Type: Aerobic + electromyostimulation Duration: 12 weeks Frequency: 2 days/week Intensity: >95 - 120% VO ₂ max Time: 20 – 35min/session Adherence: 98.7%	Usual care	PSQI	Improved sleep quality ($p < 0.05$)
King et al., 2008	Older adults with sleep complaints	IG: 32 CG: 27	55 years old and above	Type: Aerobic Duration: 48 weeks Frequency: 5 days/week Intensity: 60 – 85% HRmax Time: 40 min/session Adherence: 74%	Health education classes	PSQI PSG	PSQI outcomes were improved but not significant ($p = 0.07$). No significant group different were observed

							for all PSG outcomes.
Kline et al., 2011	Obstructive sleep apnoea	IG: 27 CG: 16	18-55 years old	Type: Combined aerobic and resistance training Duration: 12 weeks Frequency: 6 days/week Intensity: 60% HRR Time: Not reported Adherence: 87%	Stretching activity	PSQI PSG	PSQI significantly improved ($p = 0.01$) but all PSG outcomes were not significant
Leonel et al., 2022 (a)	None	IG: 9 CG: 13	20-50 years old	Type: Combined aerobic and resistance training (non-periodized) Duration: 16 weeks Frequency: 3 days/week Intensity: Moderate intensity Time: 60 min/session Adherence: 67.12%	Usual care	PSQI	No significant different on PSQI
Leonel et al., 2022 (b)	None	IG: 13 CG: 13	20-50 years old	Type: Combined aerobic and resistance training (linear periodized) Duration: 16 weeks Frequency: 3 days/week Intensity: Not reported Time: 60 min/session Adherence: 58.97%	Usual care	PSQI	No significant different on PSQI
Lins-Filho et al., 2023	Obstructive sleep apnoea	IG: 17 CG: 19	18 years old and above	Type: Aerobic Duration: 12 weeks Frequency: 3 days/week Intensity: 50 – 95% HRmax Time: 45 min/session	Stretching activity	PSQI PSG	TST and SE significantly improved

				Adherence: 97.9%			($p = 0.049$; $p = 0.026$, respectively).
Newton et al., 2014	Women with vasomotor symptoms	IG: 105 CG: 138	40-62 years old	Type: Yoga Duration: 12 weeks Frequency: 1 day/week Intensity: – Time: 90 min/session Adherence: 80%	Usual care	PSQI	No significant different on PSQI
Quist et al., 2019 (a)	None	IG: 35 CG: 18	20-45 years old	Type: Aerobic Duration: 24 weeks Frequency: 5 days/week Intensity: Self-chosen Time: 45 min/session Adherence: >90%	Usual care	Actigraphy	No significant changes in TST ($p = 0.54$)
Quist et al., 2019 (b)	None	IG: 39 CG: 18	20-45 years old	Type: Aerobic Duration: 24 weeks Frequency: 5 days/week Intensity: Moderate (49% VO ₂ peak-reserve) Time: 55 min/session Adherence: >90%	Usual care	Actigraphy	No significant changes in TST ($p = 0.36$)
Quist et al., 2019 (c)	None	IG: 38 CG: 18	20-45 years old	Type: Aerobic Duration: 24 weeks Frequency: 5 days/week Intensity: High (65% VO ₂ peak-reserve) Time: 40 min/session Adherence: >90%	Usual care	Actigraphy	No significant changes in TST ($p = 0.57$)

Reid et al., 2010	Older adults with insomnia	IG: 10 CG: 7	55 years old and above	Type: Aerobic + sleep hygiene education Duration: 16 weeks Frequency: 4 days/week Intensity: 55 – 75% HRmax Time: 40 min/session Adherence: 70.6%	Usual care	PSQI	Sleep quality improved ($p < 0.001$)
Rshikeshan et al., 2018	None	IG: 37 CG: 35	18-60 years old	Type: Yoga Duration: 14 weeks Frequency: 5 days/week Intensity: – Time: 90 min/session Adherence: Not reported	Walking	PSQI	Sleep quality was improved ($p < 0.05$)
Sternfeld et al., 2014	Women with frequent vasomotor symptoms	IG: 79 CG: 131	40-62 years old	Type: Aerobic Duration: 12 weeks Frequency: 3 days/week Intensity: 50 – 70% HRR Time: 40 – 60 min/session Adherence: Not reported	Usual care	PSQI	Sleep quality was improved ($p = 0.01$)
Tan et al., 2016	Chronic insomnia symptoms	IG: 24 CG: 21	30-65 years old	Type: Aerobic Duration: 24 weeks Frequency: 1 – 5 days/week Intensity: High (60 – 75% HRmax) Time: 30 – 60 min/session Adherence: Not reported	Usual care	Piezoelectric bed sensor	Lower SOL ($p = 0.010$)

IG = Intervention group; *CG* = control group; *HRR* = Heart Rate Reserve; *HRmax* = Maximum Heart Rate; *Vo₂max* = Maximum Oxygen Consumption; *TST* = Total Sleep Time; *PSQI* = Pittsburgh Sleep Quality Index; *PSG* = Polysomnography; *SE* = Sleep Efficiency; *MICT* = Moderate Intensity Continuous Training; *HIIT* = High Intensity Interval Training; *SOL* = Sleep Onset Latency; *IRM* = One Repetition Maximum; *Reps* = Repetition

4.3 Study Quality for Individuals Study

Table 4.2 summarizes the study quality across all studies included in the meta-analysis. The median risk of bias score was 8. None of the studies implemented group allocation concealment. Additionally, there was a notable absence of activity monitoring in the control groups and limited reporting on adherence to the interventions. These factors collectively contributed to an elevated risk of bias in each study.

Table 4.2
Study Quality in Individual Studies

Author/ year	Eligibility criteria specified	Randomization specified	Allocation concealment	Groups similar at baseline	Blinding of assessor	Adherence 85%	Adverse event	Attendance reported	Intention to treat analysis	Between group primary outcome	Between group secondary outcome	Reported all outcomes	Activity monitoring in control group	Exercise intensity remained constant	Reported exercise volume and energy expenditure	TOTAL
Abd El-Kader et al., 2020	1	0	0	1	1	0	0	0	0	1	1	1	0	0	1	7
Aguirre-Betolaza et al., 2020	1	1	0	1	1	0	0	0	1	1	0	1	0	0	1	8
Aibar-Almazán et al., 2019	1	1	0	1	1	1	1	1	0	1	1	1	0	0	0	10
Alarcón-Gómez et al., 2021	1	1	0	1	0	0	1	0	0	1	1	1	0	1	0	8
Atlantis et al., 2006	1	1	0	1	0	0	1	0	1	1	1	1	0	1	1	10
Brandão et al., 2018	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	13
Buchanan et al., 2017	1	1	0	1	1	0	0	1	0	1	1	1	0	0	1	9

Dieli-Conwright et al., 2021	1	1	0	1	0	1	1	1	1	1	1	1	0	1	1	12
Drew et al., 2021	1	1	0	1	1	0	0	0	1	1	1	1	0	0	0	8
Duncan et al., 2020	1	1	0	1	1	0	0	0	1	1	1	1	0	0	0	8
Ebrahimi et al., 2017	1	1	0	1	0	0	0	0	0	1	0	1	0	1	1	7
Ezpeleta et al., 2023	1	0	0	1	1	0	0	0	0	1	1	1	0	1	1	8
Innes et al., 2012	1	1	0	1	0	0	1	1	0	1	1	1	0	0	0	8
Irwin et al., 2014	1	1	0	1	1	0	0	1	1	1	1	1	0	0	0	9
Jurado-Fasoli et al., 2020	1	1	0	1	1	1	1	1	0	1	1	1	0	1	1	12
King et al., 2008	1	0	0	1	1	0	0	1	1	1	1	1	0	0	1	9
Kline et al., 2011	1	1	0	1	0	0	1	1	1	1	1	1	0	1	1	11
Leonel et al., 2022	1	1	0	1	1	0	1	1	1	1	1	1	0	1	1	12
Lins-Filho et al., 2023	1	1	0	1	1	1	0	1	0	1	1	1	0	0	1	10

Newton et al., 2014	1	1	0	1	0	0	1	1	1	1	1	1	0	0	0	9
Quist et al., 2019	1	1	0	1	0	1	0	1	0	1	0	1	0	1	1	9
Reid et al., 2010	1	0	0	1	0	0	0	1	0	1	0	1	1	1	1	8
Rshikesan et al., 2018	1	1	0	1	0	0	0	0	0	1	1	1	0	0	0	6
Sternfeld et al., 2014	1	1	0	1	1	0	1	0	1	1	1	1	0	1	1	11
Tan et al., 2016	1	1	0	1	0	1	0	1	1	1	0	1	0	1	1	10

4.4 Meta-Analysis Results

4.4.1 Effects of Exercise on Subjective Sleep Quality Compared to Control Group

A total of 20 studies were included in the meta-analysis for the PSQI measurements. The pooling results of these studies suggest that exercise had a statistically significant effect on sleep quality vs. control with a pooled MD of -1.63 (95% CI -2.31 to -0.96 , $p < 0.00001$) (Figure 4.2). Heterogeneity among studies was found to be substantially high ($I^2 = 74\%$). A sub-group analysis needs to be conducted to identify the source of heterogeneity.

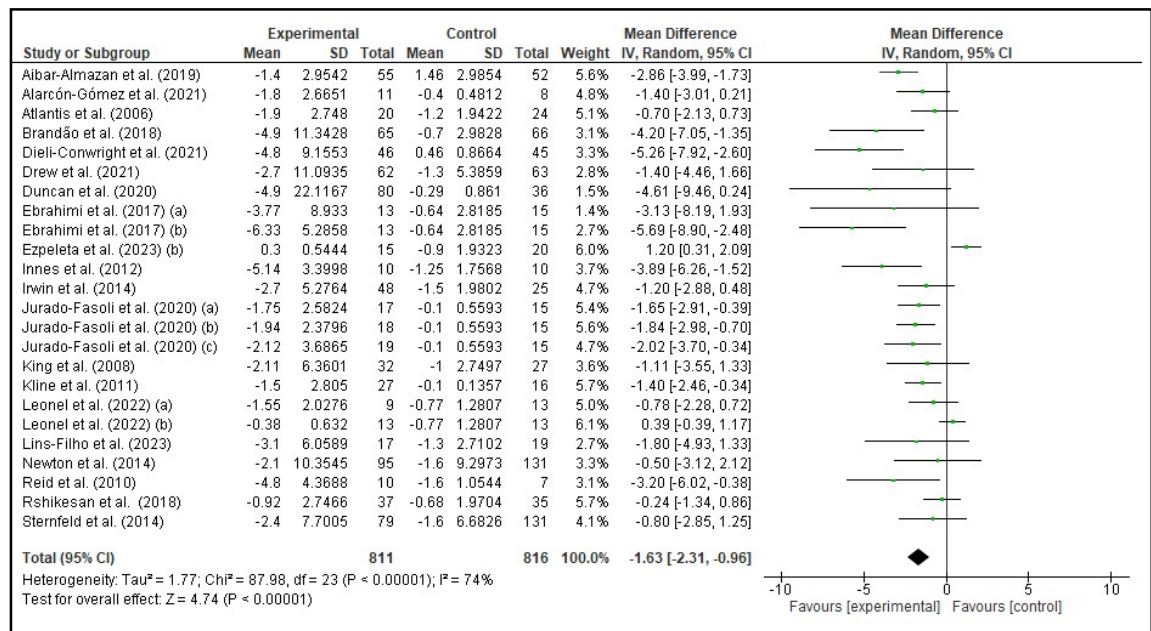


Figure 4.2 Forest plot of PSQI Scale Outcomes in Overall Analysis

4.4.2 Effects of Exercise on Objective Sleep Quality Compared to Control Group

A total of nine studies reported the data measured by Actigraphy and Polysomnography (PSG) to assess the objective sleep outcomes in participants. Of these, two studies contained two different exercise interventions; aerobic exercise and aerobic + resistance exercise (Servantes et al., 2012), aerobic exercise and yoga (Buchanan et al, 2017). Moreover, two studies lacked the data of TST, five studies lacked WASO data, one study lacked the data of SE, and three studies did not provide SOL data.

Remarkably, we discovered that exercise had a significantly positive impact on participants' physiological SE (MD 3.62; 95% CI 1.31 to 5.94; $p = 0.002$; $I^2 = 78\%$) in comparison to the control intervention (Figure 4.6). Other findings reveal that the participants who undergo exercise intervention is likely to report slightly lower SOL (MD -2.17; 95% CI -5.93 to 1.59; $p = 0.26$; $I^2 = 78\%$) (Figure 4.5), less time of WASO (MD -3.08; 95% CI -7.48 to 1.32; $p = 0.17$; $I^2 = 63\%$) (Figure 4.4), as well as slight increase in TST (MD 1.16; 95% CI -11.14 to 13.45; $p = 0.85$; $I^2 = 74\%$) (Figure 4.3) when compared with the control group. However, none of these differences between the two groups was statistically significant (except for SE).

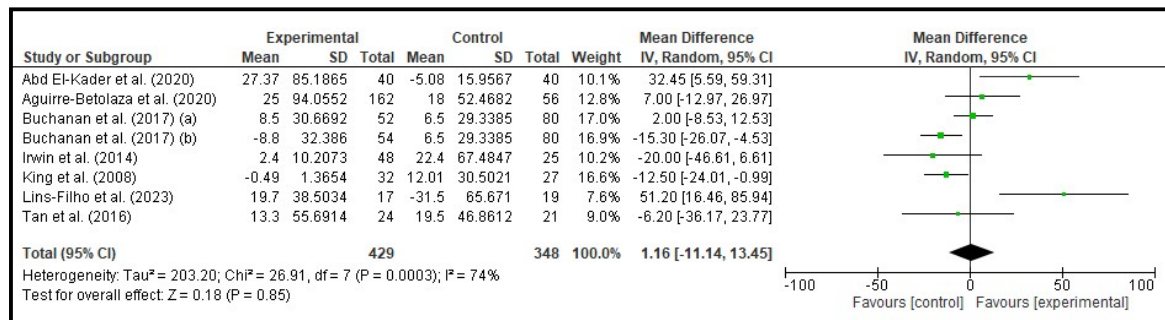


Figure 4.3 Forest Plot of TST Outcomes in Overall Analysis

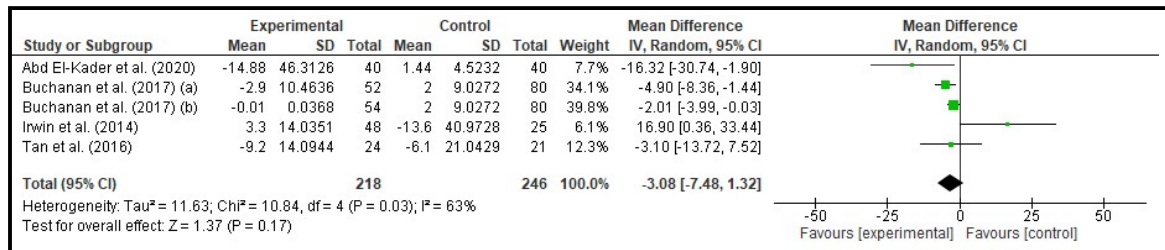


Figure 4.4 Forest Plot of WASO Outcomes in Overall Analysis

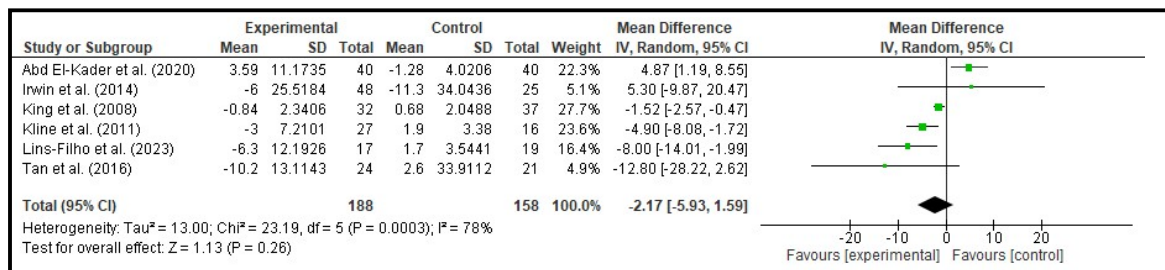


Figure 4.5 Forest Plot of SOL Outcomes in Overall Analysis

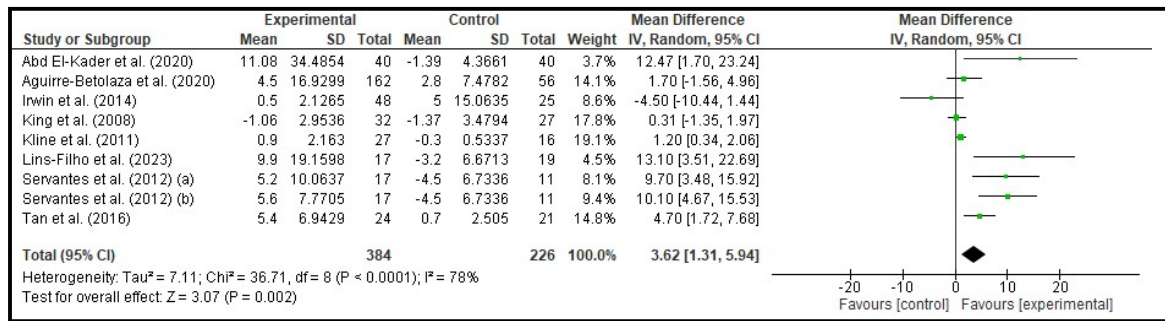


Figure 4.6 Forest Plot of SE Outcomes in Overall Analysis

4.4.3 Sub-Group Analysis of Subjective Sleep Quality

We further performed subgroup analyses of PSQI measurements in 20 studies based on the following variables: the type of exercise (aerobic, combined aerobic and resistance, or mind-body exercise), BMI classification (overweight or obese), and sleep condition (normal or sleep disorder).

4.4.3.1 Sub-group analysis based on types of exercises

Regarding the exercise type, aerobic exercise (MD -1.32; 95% CI -2.51 to -0.13; $p = 0.03$), combined aerobic and resistance training (MD -1.55; 95% CI -2.71 to -0.40; $p = 0.008$) and mind-body exercise (MD -2.30; 95% CI -3.90 to -0.69; $p = 0.005$) all had favorable effects on subjective sleep quality (Figure 4.7). The test for subgroup differences indicated that there is no statistically significant subgroup effect ($p = 0.63$), suggesting that type of exercise does not modify the effect of exercise in comparison to control on sleep quality. However, the I^2 value is considerably high for aerobic, combined aerobic and resistance, and mind-body exercise, ($I^2 = 74\%$, $I^2 = 79\%$ and $I^2 = 82\%$ respectively).

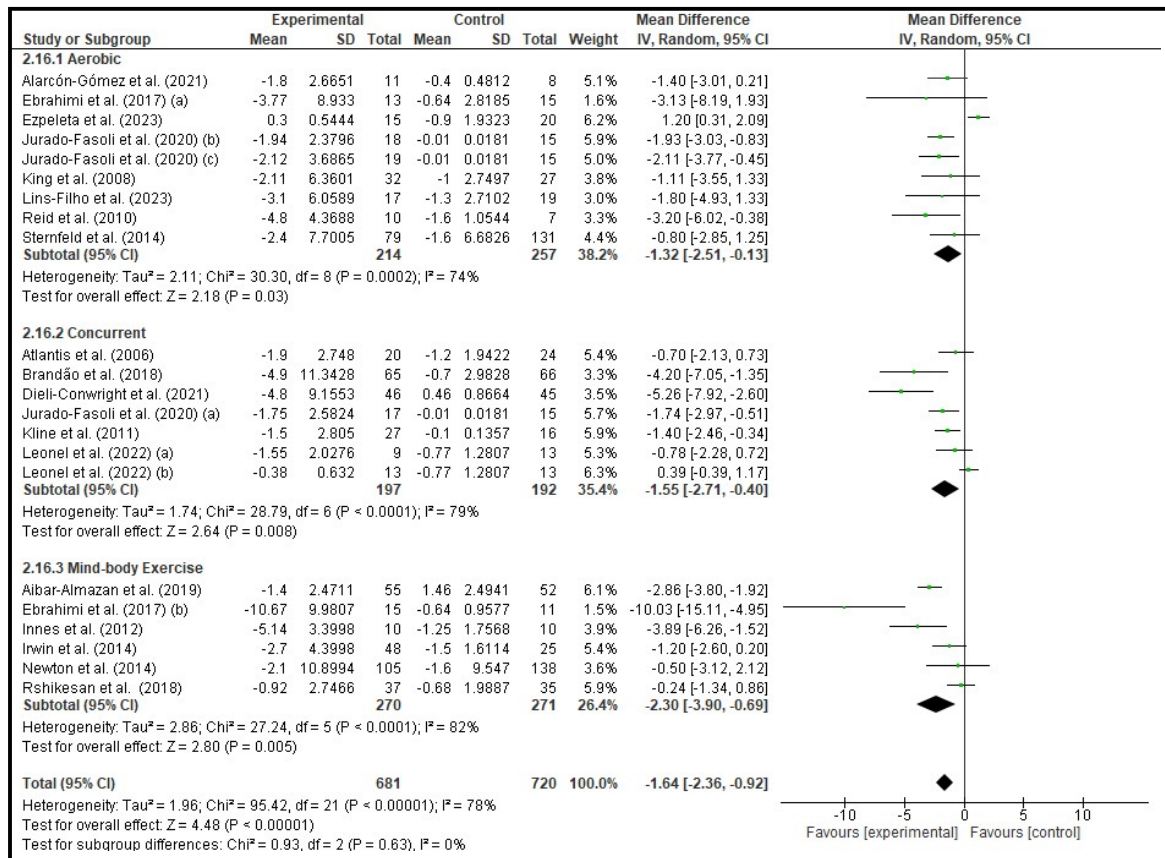


Figure 4.7 Forest Plot of PSQI Scale Outcomes in Subgroup Analysis Stratified by the Type of Exercise Intervention

4.4.3.2 Sub-group analysis based on BMI classification of the participants

Considering subgroups by BMI classification, overweight subgroup (MD -1.86 ; 95% CI -2.41 to -1.32 ; $p < 0.00001$) and obese subgroup (MD -1.21 ; 95% CI -2.35 to -0.07 ; $p = 0.04$) both shows significant effect on sleep quality (Figure 4.8). The difference between these two subgroups was not statistically significant ($p = 0.31$) indicating that BMI classification does not modify the effect of exercise in comparison to control on sleep quality. However, a smaller number of trials and participants contributed data to the obese subgroup than to the overweight subgroup, meaning that the analysis may not be able to detect subgroup differences. Remarkably, heterogeneity for overweight subgroups appeared to be low ($I^2 = 23\%$) while obese subgroups showed significant heterogeneity ($I^2 = 82\%$).

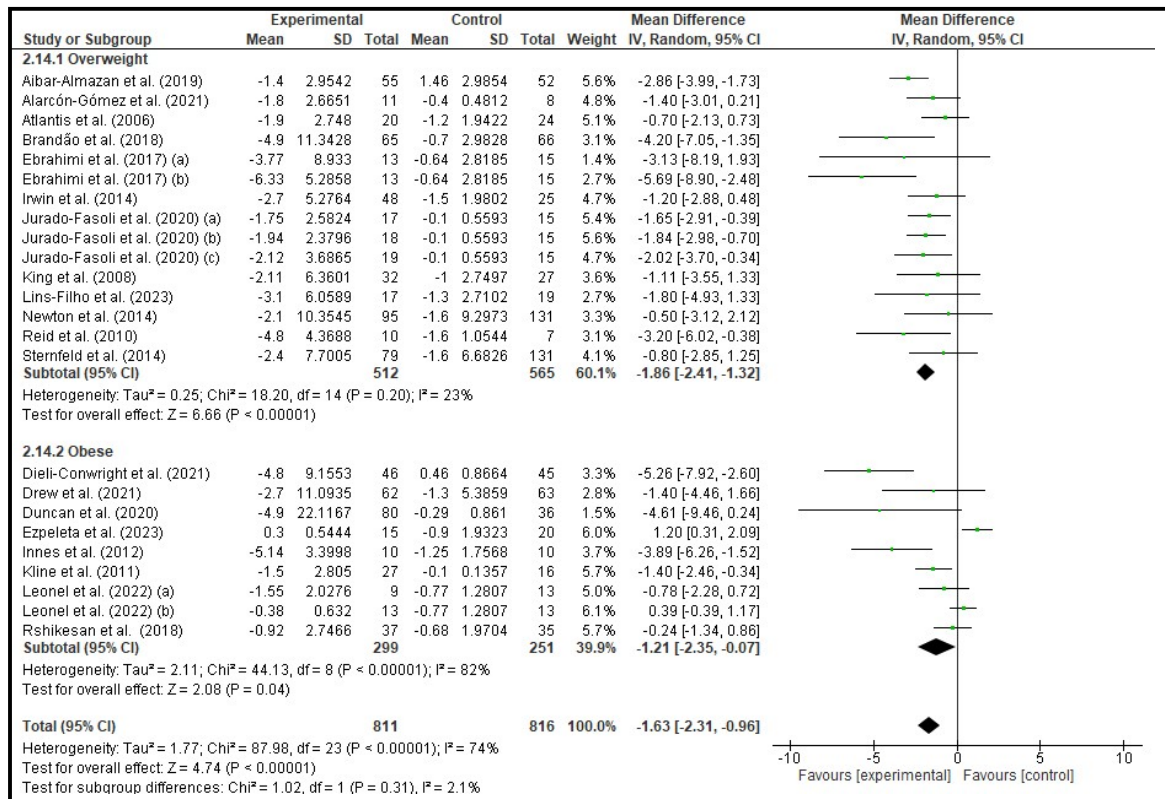


Figure 4.8 Forest Plot of PSQI Scale Outcomes in Subgroup Analysis Stratified by BMI Classification

4.4.3.3 Sub-group analysis based on sleep condition of the participants

Regarding sleep condition subgroup analysis, the results showed beneficial improvements of sleep quality in trials involving normal participants who do not have any sleep disorder and any other diseases (MD -1.20 ; 95% CI -2.00 to -0.40 ; $p = 0.003$) and trials involving participants that have sleep disorder (MD -1.49 ; 95% CI -2.27 to -0.71 ; $p = 0.0002$) (Figure 4.9). The test for subgroup differences indicated that there is no statistically significant subgroup effect ($p = 0.61$), suggesting that sleep condition does not modify the effect of exercise in comparison to control on sleep quality. However, due to fewer trials and participants contributing data to the sleep disorder subgroup compared to the normal subgroup, the analysis might lack the statistical power to detect differences between these subgroups. Surprisingly, there was no heterogeneity observed among sleep disorder subgroups ($I^2 = 0\%$), whereas moderate heterogeneity was evident among normal subgroups ($I^2 = 64\%$).

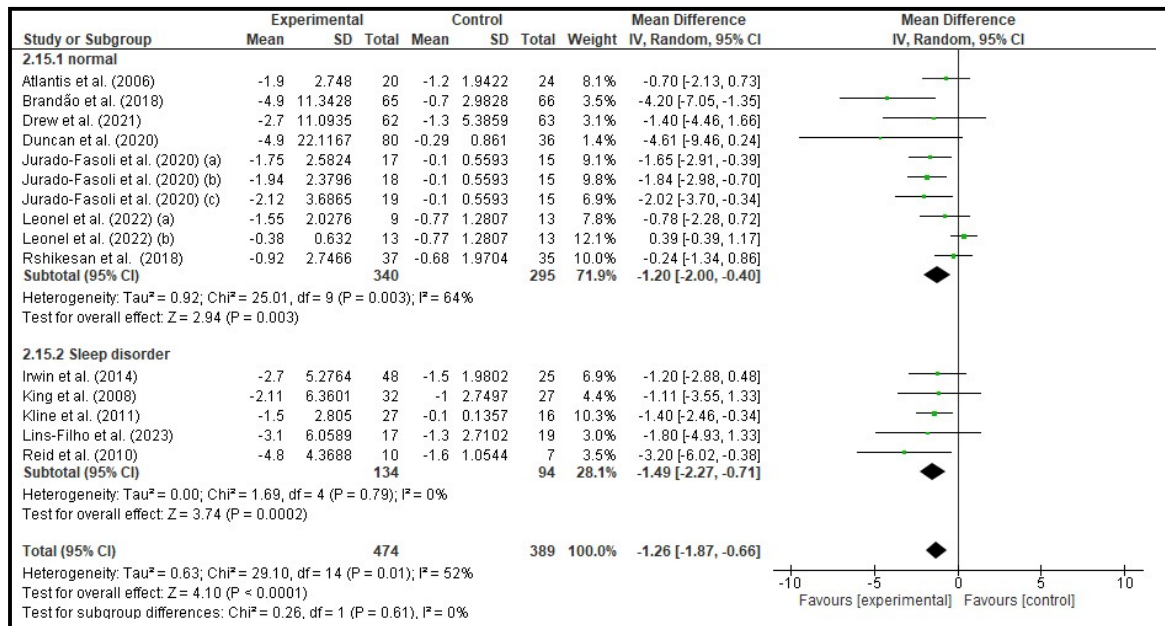


Figure 4.9 Forest Plot of PSQI Scale Outcomes in Subgroup Analysis Stratified by Sleep Condition

CHAPTER 5

DISCUSSION

5.1 Overall Effect on Subjective Sleep Quality

The overall analysis demonstrated that exercise interventions were associated with significant improvements in subjective sleep quality among individuals with overweight and obesity ($p < 0.00001$), although high heterogeneity was observed across studies. A modest but statistically significant decrease in global PSQI scores was found in the exercise groups, with a mean reduction of 2.54 points, corresponding to a 32.93% improvement in sleep quality. This finding is consistent with recent literature showing clinically meaningful reductions in PSQI scores following exercise. For example, Zhou et al. (2025) report that regular exercise yielded a pooled PSQI decrease of 1.77 points ($p < 0.001$) in general adult samples (X. Zhou et al., 2025). Likewise, Kawinchotpaisan et al. (2025) found that high-intensity interval training (HIIT) produced an even larger PSQI reduction of -3.5 in obese patients (Kawinchotpaisan et al., 2025b). These results echo our findings, suggesting that overweight and obese individuals experience notable improvements in self-reported sleep quality (PSQI and related scales) after exercise.

The significant improvements in subjective sleep quality observed in this review are likely attributable to several converging physiological and psychological mechanisms. Regular exercise is known to modulate the autonomic nervous system by enhancing parasympathetic activity and reducing sympathetic arousal (Thayer et al., 2020), which promotes relaxation and facilitates sleep onset and maintenance. Additionally, exercise improves sleep quality by increasing melatonin production (Carlson et al., 2019) and reducing cortisol levels (Park et al., 2023). These hormonal changes contribute to relaxation and make it easier for individuals to fall asleep, thereby improving their sleep quality (Mahtar et al., 2025). Hence, these findings possibly explain why exercise serves as an effective strategy for improving subjective sleep quality within this population.

The average baseline for PSQI score for the exercise group was 8.66, indicating poor sleep quality. Since this study population includes overweight and obese individuals, we assumed they likely lead a sedentary lifestyle, which is a common characteristic of

individuals in this demographic. A sedentary lifestyle is a key factor contributing to poor sleep quality. Research supports that prolonged sedentary behavior is associated with an increased body mass index (BMI) and a higher risk of obesity (Yates et al., 2012). Existing literature suggests that prolonged sedentary behavior is correlated with an increased risk of insomnia, poor sleep quality, and other sleep disturbances (Levenson et al., 2016). Hence, this explains the poor baseline sleep quality observed in the exercise group. After the intervention, the average PSQI score improved significantly to 6.12, reflecting an enhancement in sleep quality. These findings suggest that while exercise positively impacted sleep, adjustments to the exercise program, together with other confounding factors such as healthy food, supplement intake, and medication, may be needed for optimal sleep quality.

5.2 Overall Effect on Objective Sleep Quality

Objective measures of sleep (e.g. actigraphy or polysomnography) showed smaller improvements than subjective reports, but still tended to favor exercise. TST improved by 2.86%, showing a trend toward longer sleep duration, although it remained within the 'poor' category. SOL improved by 12%, retaining its 'good' classification. SE improved more notably of 4.34%, crossing into the 'good' category. WASO improved by 5.64%, although it still remained categorized as 'poor'. While these changes reflect a trend towards improved sleep quality, statistical analysis revealed that these changes were not significant except for SE.

In particular, pooled analyses often found increased sleep efficiency in exercisers. For example, Zhou et al. (2025) found that exercise increased objective sleep efficiency by about 4.8% (MD +4.81%, 95% CI 2.32–7.30) (X. Zhou et al., 2025). Similarly, Iftikhar et al. (2014) reported a 5.75% mean increase in sleep efficiency across trials of exercise in sleep apnea patients (Iftikhar et al., 2014a). In controlled trials, Tan et al. (2016) found that overweight/obese men engaging in six months of aerobic exercise had significantly higher actigraphic sleep efficiency and shorter wake-after-sleep time at follow-up than controls (Tan et al., 2016a).

By contrast, changes in objective metrics like total sleep time or latency are less consistently reported. Kline et al. (2011) reported improvements in certain

polysomnographic stages, including increased deep sleep, following combined training; however, such effects have not been consistently observed across studies (C. E. Kline et al., 2011c). In many studies, exercise had few significant effects on most physiological parameters (except efficiency) (Xie et al., 2021c). Thus, while exercise may modestly enhance objective sleep quality (often by improving continuity and efficiency), these effects are generally smaller than subjective gains. The small changes seen in the objective results may be because it is hard to noticeably change sleep stages or how long people sleep.

5.3 Comparison of Subjective vs. Objective Sleep Outcomes

Across studies, subjective sleep gains from exercise typically exceed objective gains. This subjective–objective discrepancy is well documented in the literature. For instance, Xie et al.’s meta-analysis found large pooled improvements on self-reported measures (PSQI, ISI, ESS) with exercise (PSQI MD -2.19 , 95% CI -2.96 to -1.41), whereas physiological measures (actigraphy or PSG) showed limited significant changes beyond sleep efficiency (Xie et al., 2021a). In the present review, a similar pattern emerged: participants often reported feeling better rested or less disturbed, even when changes in actigraphy and PSG data were modest. Although notable improvements were observed in subjective sleep outcomes, our meta-analysis identified significant changes in only two objective sleep parameters, which is WASO and SE. This discrepancy highlights a potential gap between perceived and physiological sleep, often referred to as sleep misperception (Buysse, 2014).

Several psychological and physiological mechanisms may explain this phenomenon. First, the discrepancy between subjective and objective sleep measures could be due to the psychological factors associated with exercise. Exercise is known to improve mood, reduce anxiety, and promote relaxation, which may lead to enhanced sleep perception (Rebar et al., 2015). These affective benefits can alter individuals’ cognitive appraisal of sleep, leading to more favorable subjective evaluations even in the absence of substantial physiological change. This is consistent with cognitive models of insomnia, which suggest that sleep perception is strongly influenced by pre-sleep cognitive arousal, attentional bias, and dysfunctional beliefs about sleep (Harvey, 2002). Exercise may attenuate these processes by reducing somatic tension and intrusive thoughts, thereby improving perceived

sleep quality. This psychological mechanism may play a significant role in subjective sleep assessments, further highlighting the importance of using both subjective and objective measures to fully understand the effects of exercise on sleep.

In addition, the concept of sleep state misperception provides a theoretical framework for understanding discrepancies between subjective and objective sleep (Thorpy, 1990). Individuals particularly with insomnia or obesity-related sleep disturbances, may underestimate total sleep time and overestimate wakefulness due to heightened nocturnal arousal and altered interoceptive awareness (Harvey & Tang, 2012; Perlis et al., 1997). Exercise may reduce this hyperarousal and recalibrate perception of sleep continuity without necessarily producing large measurable changes in sleep architecture (Driver & Taylor, 2000; Harvey & Tang, 2012; Kredlow et al., 2015). Consequently, improvements in subjective sleep may reflect more accurate perception rather than purely placebo-driven effects.

Physiologically, exercise influences multiple systems that indirectly enhance sleep experience without always producing detectable changes in standard polysomnographic metrics. For example, exercise-induced reductions in hypothalamic–pituitary–adrenal (HPA) axis activity and sympathetic nervous system activation can promote relaxation and facilitate sleep onset (Kredlow et al., 2015). Similarly, thermoregulatory effects—such as the post-exercise decline in core body temperature—are associated with increased sleep propensity and perceived sleep depth (Driver & Taylor, 2000; Krauchi & Deboer, 2010). However, these changes may not always translate into large shifts in macro-level sleep parameters (e.g., total sleep time), particularly in short-duration interventions or studies with limited sensitivity to subtle changes in sleep architecture (Kredlow et al., 2015; Morin et al., 2006).

Methodological factors may further contribute to the observed discrepancy. Objective sleep assessments, particularly polysomnography, are often conducted over a limited number of nights and may be affected by the “first-night effect,” which can distort typical sleep patterns (Agnew et al., 1966). Actigraphy, while useful for long-term monitoring of sleep–wake patterns in naturalistic settings, may also lack sensitivity in detecting subtle changes in sleep architecture (Ancoli-Israel et al., 2003; Sadeh, 2011). In contrast, subjective measures such as the PSQI capture habitual sleep experiences over

extended periods, making them more responsive to gradual improvements associated with behavioural interventions like exercise (Buysse et al., 1989).

Taken together, the discrepancy between subjective and objective sleep outcomes likely reflects a combination of psychological, physiological, and methodological factors rather than a true inconsistency in treatment effects. Importantly, both domains demonstrated positive trends in response to exercise in the present analysis, with significant reductions in self-reported sleep disturbances alongside modest improvements in objective measures such as sleep efficiency and WASO. Clinically, these findings suggest that even in the absence of large physiological changes, exercise interventions may yield meaningful improvements in perceived sleep quality, which is strongly associated with overall well-being and daytime functioning (Buysse, 2014).

5.4 Exercise Modality (Subgroup Analysis)

The analysis of subgroup differences showed no statistically significant effect ($p = 0.63$), indicating that the type of exercise does not alter the impact of exercise versus control on sleep quality. Nevertheless, all exercise types led to significant improvements in subjective sleep quality. This finding is consistent with prior meta-analytic evidence indicating that exercise improves sleep outcomes regardless of specific modality, with overall effects being more dependent on engagement in physical activity rather than exercise type per se (Kredlow et al., 2015; Yang et al., 2012). Nevertheless, differences in physiological and psychological mechanisms may explain subtle variations in how each modality influences sleep-related processes.

Aerobic exercise (e.g., walking, cycling, HIIT) has been consistently linked with improved sleep quality through thermoregulatory and circadian mechanisms. Increases in core body temperature during aerobic activity followed by post-exercise cooling may facilitate sleep onset by enhancing heat dissipation, a process closely linked to sleep initiation (Kredlow et al., 2015). Aerobic exercise has also been shown to improve mood and reduce symptoms of anxiety and depression, which are known mediators of sleep disturbance (Yang et al., 2012). These pathways may explain why aerobic training consistently demonstrates improvements in subjective sleep quality across clinical and non-clinical populations. Meta-analyses focusing on aerobic training report significant pooled

effects on sleep outcomes; for example, Rubio-Valles and Ramos-Jiménez (2025) found that aerobic exercise produced an overall improvement in sleep quality (pooled MD -2.51 , 95% CI -4.80 to -0.23 on composite sleep scores) (Rubio-Valles & Ramos-Jimenez, 2025). Supporting this, Mahtar et al. (2025) also reported consistent improvements in subjective sleep quality with aerobic interventions. In practice, long-term aerobic programs have reduced insomnia symptoms; for instance, Tan et al. (2016) showed that six months of home-based aerobic training significantly reduced sleep-onset latency and subjective insomnia severity in overweight and obese men.

Combined aerobic and resistance training appears similar effectiveness. This type of exercise may provide broader physiological stimulation by simultaneously targeting cardiovascular fitness, muscular strength, and metabolic function (Garber et al., 2011). This multimodal stimulus could theoretically enhance sleep by integrating multiple recovery demands, although empirical evidence suggests that its effects are generally comparable rather than superior to single-modality training (Garber et al., 2011; C. E. Kline, 2014). The absence of significant subgroup differences in this review supports that having more combined physiological benefits do not necessarily translate into greater improvements in subjective sleep outcomes. These effects may explain why mind–body interventions often appear particularly effective in subjective sleep measures, although the current subgroup analysis indicates that these benefits are not statistically superior to other modalities.

Mind–body exercises such as yoga and Tai Chi may improve sleep through distinct psychophysiological mechanisms, particularly via reductions in sympathetic nervous system activity and psychological arousal. Although few studies have tested these exclusively in obese populations, broader reviews indicate they are at least as effective as conventional exercise for perceived sleep. These practices have been shown to reduce perceived stress, enhance parasympathetic activation, and improve emotional regulation, all of which are strongly linked to sleep quality (Cramer et al., 2013; Wang et al., 2013). A systematic review and meta-analysis of yoga interventions reported significant improvements in sleep outcomes, particularly in populations with elevated stress or insomnia symptoms (Cramer et al., 2013). Similarly, Tai Chi has been associated with improved sleep quality and reduced sleep disturbances, likely mediated by relaxation and attentional control mechanisms (Wang et al., 2013). These effects may explain why mind–

body interventions often appear particularly effective in subjective sleep measures, although the current subgroup analysis indicates that these benefits are not statistically superior to other modalities.

Overall, while the present findings indicate no significant differences between exercise modalities, the underlying mechanisms suggest that each type of exercise may influence sleep through partially distinct but overlapping biological and psychological pathways. The consistency of benefits across modalities aligns with the broader literature suggesting that adherence to regular exercise, rather than exercise type alone, is the primary determinant of sleep improvement (Kredlow et al., 2015; Yang et al., 2012).

5.5 BMI Classification (Overweight vs. Obese)

Our subgroup analysis explored whether effects differed between overweight (BMI 25–29.9) and obese (BMI ≥ 30) individuals. The available data did not clearly favor one group; both subgroups appeared to benefit from exercise. In our meta, effect sizes for sleep improvement were similar across BMI categories. The difference between the two subgroups was not statistically significant ($p = 0.31$), suggesting that BMI classification does not influence the effect of exercise versus control on sleep quality.

Prior studies offer limited direct comparisons, but examples exist in each category. For instance, Tan et al. (2016) predominantly studied obese men (93% BMI ≥ 25) with insomnia and found significant sleep improvements (Tan et al., 2016), while an intervention in overweight/obese women also improved sleep quality (Buğday et al., 2025). Mendelson et al. (2016) found that exercise boosted sleep duration and efficiency in obese adolescents, implying no loss of efficacy at higher adiposity (Mendelson et al., 2016).

The underlying mechanism may vary across BMI classifications. Individuals with obesity often experience more severe sleep disturbances (e.g., OSA), so reductions in body fat from exercise could lead to greater absolute improvements in sleep quality. In contrast, overweight individuals may already have higher baseline activity levels, making them more responsive to the additional benefits of structured exercise. Until more specific research results are available, it is reasonable to recommend exercise for individual in all BMI ranges. This is because those with higher BMI could also experience extra benefits, for example,

improvements in other health problems they might have (like obstructive sleep apnea, OSA), and those improvements could further help them sleep better.

5.6 Sleep Conditions (With vs. Without Sleep Disorders)

We also examined whether baseline sleep pathology moderated exercise effects. The test for subgroup differences indicated that there is no statistically significant subgroup effect ($p = 0.61$), suggesting that sleep condition does not modify the effect of exercise in comparison to control on sleep quality. Both groups yield significant improvements after exercise interventions.

Overweight/obese individuals with diagnosed sleep disorders (insomnia or sleep apnea) generally showed robust improvements. In patients with chronic insomnia, for example, aerobic exercise produced meaningful gains: Tan et al. (2016) reported that exercise “mitigated difficulty initiating sleep” in overweight/obese men, with significant reductions in objective sleep-onset latency and subjective night awakenings (Tan et al., 2016). Similarly, multiple trials in obese individuals with OSA demonstrate that exercise training significantly reduces apnea severity and daytime sleepiness (Iftikhar et al., 2014). Iftikhar et al. (2014) meta-analyzed 5 trials in OSA patients and found exercise lowered the apnea–hypopnea index (AHI) by an average of 6.3 events/hour ($p < 0.001$) and increased sleep efficiency by nearly 6% (Iftikhar et al., 2014). Kline et al. (2011) likewise documented large AHI reductions and improved PSQI scores after 12 weeks of combined training in moderately obese OSA patients (C. E. Kline et al., 2011c). These findings suggest that individuals with evident sleep disorders can achieve substantial benefits from exercise.

Among overweight/obese persons without formal sleep disorders, effects were generally smaller but still positive. For example, Mendelson et al. (2016) showed that an exercise program increased sleep duration by ~64 minutes and efficiency by 7.6% in obese adolescents without requiring a sleep disorder diagnosis (Mendelson et al., 2016). Thus, exercise appears to improve sleep across the spectrum: those with clinical sleep conditions may experience larger absolute improvements (partly because baseline deficits are greater), but even those without diagnosable disorders report better sleep quality and duration. Clinicians should note that exercise is likely beneficial whether or not a sleep disorder is

present, but the mode of intervention might be tailored (e.g. aerobic training for insomnia symptoms, combined training for OSA).

CHAPTER 6

CONCLUSION

6.1 Clinical Implications

These findings have clear implications for practice. Exercise should be emphasized as a non-pharmacological strategy for improving sleep in overweight and obese patients. Clinicians can confidently recommend regular exercise knowing it can yield better sleep quality and efficiency. Specifically, programs combining aerobic exercise with resistance training is most potent; such regimens will also benefit metabolic health and weight management. Importantly, exercise can complement standard sleep disorder treatments: for example, adding exercise may help OSA patients achieve greater symptom relief beyond Continuous positive airway pressure (CPAP) or weight loss alone (Iftikhar et al., 2014). In primary care, discussing sleep outcomes when counselling on exercise may motivate patients, since better sleep is a near-term, personally relevant benefit. When prescribing exercise, practitioners should consider feasibility: a range of intensities and formats have shown benefit, so tailoring to patient preferences and physical capacity is advisable. Given the bidirectional link between poor sleep and obesity, improving sleep via exercise may also facilitate weight loss and metabolic improvements over time, creating a virtuous cycle for patient health.

6.2 Future Research Directions

Several gaps and opportunities for further study emerge. First, more trials are needed that directly compare overweight versus obese subgroups and quantify any differential effects. Larger RCTs stratifying participants by BMI, age, or comorbidities would clarify how much adiposity modifies exercise benefits on sleep. Second, optimal “dosing” of exercise (intensity, duration, timing) for sleep improvement remains unclear. For instance, exploring whether morning versus evening exercise has distinct effects on sleep phase or quality (as suggested in one trial; (Rubio-Valles & Ramos-Jimenez, 2025) could guide scheduling recommendations. Third, long-term follow-up is sparse: we need to know whether sleep gains are maintained with ongoing training and whether they

translate to better outcomes (e.g. reduced incidence of insomnia or better weight maintenance). Mechanistic studies are also warranted to unpack how exercise influences sleep physiology in obesity. Investigating changes in inflammation, metabolic hormones (leptin/ghrelin), and circadian markers could explain observed benefits. Finally, research should examine how to integrate exercise into holistic sleep care. Trials combining exercise with cognitive-behavioral therapy for insomnia or CPAP for OSA could test synergistic effects. Addressing barriers to exercise (e.g. pain, fatigue) in obese patients and identifying effective motivational strategies are also important practical questions for future work.

To the best of the author's knowledge, this meta-analysis represents the first attempt to systematically investigate the effects of exercise on sleep quality in overweight and obese populations, including individuals with various comorbidities. However, we recommend further research to establish definitive conclusions regarding the effect of aerobic exercise on objective sleep quality and subgroup analyses based on obesity levels.

6.3 Limitations and Considerations

This meta-analysis presented a limitation that should be acknowledged, as it may have impacted the robustness and generalizability of the findings. One key limitation is the high risk of bias observed in the majority of the included studies, primarily due to the sample size, the lack of group allocation concealment and the absence of activity monitoring in control group. The failure to conceal group allocation may have introduced selection bias. Moreover, without activity monitoring in the control group, it is difficult to assess the extent to which participants followed the prescribed regimens, which may have led to varying intervention effects across studies. Other limitation is the variability in intensity and duration of interventions. Studies used different exercise protocols, from low to high intensity and varying durations, making it challenging to draw consistent conclusions. This diversity can affect adherence, compliance, and overall effectiveness, contributing to heterogeneity in results.

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APPENDICES

APPENDIX A

Pittsburgh Sleep Quality Inventory (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, what time have you usually gone to bed at night?
2. During the past month, how long (in minutes) has it usually takes you to fall asleep each night?
3. During the past month, what time have you usually gotten up in the morning?
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 spent in bed.)

Table A1
Scoring in PSQI

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 loudly				
f. Feel too cold				
g. Feel too hot				
h. Have bad dreams				
i. Have pain				
j. Other reason(s), please describe:				

6. During the past month, how often have you taken medicine to help you sleep (prescribed or “over the counter”)?				
7. 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
8. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?				
	Very good	Fairly good	Fairly bad	Very bad
9. During the past month, how would you rate your sleep quality overall?				
	No bed partner or room mate	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?				
	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
If you have a roommate or bed partner, ask him/her how often in the past month you have had:				
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:				

Source: The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research (Buysse et al., 1989)

APPENDIX B

Scoring the PSQI

The order of the PSQI items has been modified from the original order in order to fit the first 9 items (which are the only items that contribute to the total score). Item 10 does not contribute to the PSQI score. In scoring the PSQI, seven component scores are derived, each scored 0 (no difficulty) to 3 (severe difficulty). The component scores are summed to produce a global score (range 0 to 21). Higher scores indicate worse sleep quality.

Table B1

Component 1: Subjective Sleep Quality—Question 9

Response to Q9	Component 1 score
Very good	0
Fairly good	1
Fairly bad	2
Very bad	3

Component 1 score: _____

Table B2

Component 2: Sleep Latency—Questions 2

Response to Q2	Component 2/Q2 sub score
< 15 minutes	0
16-30 minutes	1
31-60 minutes	2
> 60 minutes	3

Table B3

Component 2: Sleep Latency—Questions 5a

Response to Q5a	Component 2/Q5a sub score
Not during past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

Table B4

Component 2: Sum up Component 2 (Q2 + Q5a)

Sum of Q2 and Q5a sub score	Component 2 score
0	0
1-2	1
3-4	2
5-6	3

Component 2 score: _____

Table B5

Component 3: Sleep Duration—Question 4

Response to C4	Component 3 score
> 7 hours	0
6-7 hours	1
5-6 hours	2
< 5 hours	3

Component 3 score: _____

Table B6

Component 4: Sleep Efficiency—Questions 1, 3, and 4

Sleep efficiency	Component 4 score
> 85%	0
75-84%	1
65-74%	2
< 65%	3

Sleep efficiency = (# hours slept/# hours in bed) X 100%

#hours slept—question 4

#hours in bed—calculated from responses to questions 1 and 3

Component 4 score: _____

Table B7

Component 5: Sleep Disturbance—Questions 5b-5j

Questions 5b to 5j should be scored as follows:	Component 5 sub score
Not during past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

Table B8

Component 5: Sum of 5b to 5j Scores

Questions 5b to 5j should be scored as follows:	Component 5 sub score
0	0
1-9	1
10-18	2
19-27	3

Component 5 score: _____

Table B9

Component 6: Use of sleep medication—question 6

Response to Q6	Component 6 score
Not during past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

Component 6 score: _____

Table B10

Component 7: Daytime dysfunction—questions 7

Response to Q7	Component 7 sub score
Not during past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

Table B11

Component 7: Daytime dysfunction—questions 8

Response to Q8	Component 7 sub score
No problem at all	0
Only a very slight problem	1
Somewhat of a problem	2
A very big problem	3

Table B12

Component 7: Sum of Q7 and Q8 sub score

Sum of Q7 and Q8 subscores	Component 7 score
0	0
1-2	1
3-4	2
5-6	3

Component 7 score: _____

Global PSQI Score: Sum of seven component scores: _____

APPENDIX C

Tool for the Assessment of Study Quality and Reporting in Exercise (TESTEX)

CRITERION	EXPLANATION	SCORING
1 – Eligibility criteria specified	Eligibility criteria should be specified and fulfilled and specific diagnostic test values should be provided for all participants	1 Point – if eligibility criteria are clearly stated and fulfilled?
2 – Randomization specified	A description of the method used to allocate subjects into treatment groups should be provided.	1 Point – if methods are described and they are truly random e.g., coin-tossing, sequence of randomly generated numbers
3 – Allocation Concealment	It should be stated if group allocation was concealed; meaning if a subject was eligible for inclusion in the trial was unaware (when this decision was made) of which group the subject would be allocated to.	1 Point – if group allocation was concealed from subjects eligible for inclusion in the trial (e.g., consent should be given before randomization)
4 – Groups similar at baseline	Baseline data of all participants who were randomized should be presented. There should be no significant difference in the measure of the severity of the treated condition between treatment groups.	1 Point – if baseline data are separated by group allocation, presented and no differences are apparent
Blinding of all therapists	This item is not scored.	No point
5 – Blinding of assessor (for at least one key outcome)	It is not always possible to blind subjects and/or therapists; however, blinding of assessors is reasonable. If assessors of	1 Point – if it is stated unambiguously that the assessor of

	primary outcome measures are blinded to the intervention allocation of the subjects, this should be stated clearly.	at least 1 primary outcome measure was blinded to group allocation
6 – Outcome measures assessed in 85% of subjects	The percentage of patients completing the study in both groups should be reported. Any adverse events (serious medical events, deaths, hospitalizations etc.) should be reported for each intervention group. The percentage of exercise sessions completed by the exercise subjects who did not withdraw from the study should be reported.	No Point – if withdrawals are >15% 1 point – if adherence>85% 1 point – if adverse events are reported 1 Point – if exercise attendance is reported Total possible – 3 Points
7 – Intention to treat analysis	When a patient withdraws, this analysis is conducted by using either the last value obtained for each of the outcome measures as a post-intervention value, or by using the baseline value as a post value. This analysis should be added to the data of those that did complete the study and an analysis conducted.	1 Point – if intention to treat analysis was performed on outcomes of interest
8 – Between-group statistical comparisons reported	Comparison of exercise versus comparator (control) group for the primary and at least one secondary outcome should be performed.	1 Point – if between-group statistical comparisons are reported for the primary outcome measure of interest 1 Point – if between-group statistical comparisons are reported for at least one secondary outcome measure

		Total possible – 2 Points
9 – Point measures and measures of variability for all reported outcome measures	Point estimates should be provided for all outcomes, otherwise this could be deemed selective outcome reporting.	1 Point – if all outcomes are reported with point estimates
10 – Activity monitoring in control groups	Between-group differences may be diluted if control subjects crossover to intervention. As many as one third of subjects do this, so some measure e.g., exercise diary or activity monitoring should be supplied so this effect can be measured and quantified.	1 Point – if control subjects are asked to report their levels of physical activity and data are presented
11 – Relative exercise intensity remained constant	Exercise intensity is considered by many to be the best stimulus for adaptation. Once patients begin an exercise program at a set intensity they will begin to adapt. Throughout the study duration the relative intensity will fall in those that do adapt. Therefore, periodic assessment of exercise capacity should be conducted and the intensity titrated up (or in those that lose fitness, titrated down) so that exercise intensity remains constant.	1 Point – if exercise load is titrated to keep relative intensity constant
12 – Exercise volume and energy expenditure	Exercise parameters: session and program duration, session frequency, exercise training intensity and modality should be clearly reported.	1 Point – if exercise volume and energy expenditure can be calculated
	TOTAL OUT OF A POSSIBLE	15 points

AUTHOR'S PROFILE



Nurul Farah Shafiqah binti Mahtar obtained her Bachelor's Degree in Sports Science from Universiti Teknologi MARA (UiTM) in 2021 and is currently pursuing a Master of Science (Sports Science) degree at the same university. Prior to her postgraduate studies, she worked as a Research Assistant at the Faculty of Medicine, UiTM Sungai Buloh, under the supervision of Professor Sazzli Shahlan Kasim, where she gained valuable experience in clinical and exercise-related research. Her academic and research interests focus on exercise science, cardiovascular health, and the impact of physical activity on disease prevention, rehabilitation, and overall well-being.

LIST OF PUBLICATION

Mahtar, N. F. S., Ilias, N. F., Kasim, S. S., & Ismail, H. (2025). The effects of aerobic exercise on sleep quality in overweight and obese individuals: a systematic review and meta-analysis. *Fizjoterapia Polska*, 25(2), 60–69. <https://doi.org/10.56984/8zg7d1979f2>