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Time of day effect of physical activity on insomnia: a systematic literature review

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Time of day effect of physical activity on insomnia: a systematic literature review

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Abstract

The practice of regular physical activity is a common sleep hygiene recommendation as a heath promoting behaviour. However, it is not completely evident in the literature whether a specific time of day (morning vs. evening) is more advisable (or should be avoided) for exercising to improve sleep, particularly in people with insomnia. Therefore, the main aim of the present review was to verify whether a time-of-day effect exists when exploring the impact of physical activity on insomnia.

A systematic literature search was performed using PubMed electronic database. The terms “Physical Activity” and “Insomnia” were entered in the search engine and the following filters were selected: Text Availability: Full Text; Species: Humans; Language: English, French and Portuguese; Age: Adult (19-44 years) and middle aged (45-64 years); Publication date (custom range): start 2000/1/1 end 2022/3/11. The exclusion criteria were: articles with abstracts that did not refer insomnia or physical activity, studies focusing on specific diseases, populations or life stages, articles evaluating other therapeutic strategies such as cognitive-behavioural therapy or pharmacological interventions, studies not exploring the time-of day effect of physical activity on sleep of individuals with insomnia.

Considering the nine eligible studies selected for further analysis, it was observed that five studies explored the effects of physical activity on sleep of individuals experiencing sleep difficulties at different schedules of the day. The other four studies investigated the effect of physical activity at a specific time of day on sleep. No consistent pattern of results was observed throughout the studies analysed. Studies diverged considerably relatively to the methods applied (study design, sample sociodemographic characteristics, insomnia definition, sleep and activity assessment and time-of-day of physical activity explored) which compromised comparisons between studies and, consequently, jeopardized conclusions.

Based on the studies analysed, because of their diverging methodologies and results, it is difficult to ascertain a specific time-of-day that should be recommended or not advisable for practicing physical activity to promote or improve sleep of individuals experiencing insomnia. Further studies are needed to explore the time-of-day effect of physical activity on sleep of people experiencing insomnia.

Keywords

INSOMNIA; PHYSICAL ACTIVITY; SLEEP; TIME OF DAY

Resumo

A prática regular de atividade física é uma recomendação comum de higiene do sono, com vista à promoção da saúde. Todavia, na literatura não é evidente se existe uma altura do dia (manhã ou tarde/noite) em que seja mais aconselhável (ou que deva ser evitada) a prática de exercício físico de modo a melhorar a qualidade do sono, particularmente em pessoas com insónia. Assim, o objetivo principal desta revisão da literatura foi verificar se existia um efeito da hora do dia relativamente ao impacto da atividade física na insónia.

Realizou-se uma pesquisa sistemática de literatura na base de dados PubMed. Os termos "Physical Activity" (Actividade Física) e "Insomnia" (Insónia) foram inseridos no motor de busca com os seguintes filtros: Disponibilidade do texto: Texto completo; Espécies: humanos; Idioma: Inglês, Francês e Português; Idade: Adultos (19-44 anos) e Meia-idade (45-64 anos); Data de publicação (intervalo personalizado): 1/1/2000 a 11/3/2022. Os critérios de exclusão foram: artigos com resumos que não referissem insónia ou atividade física; estudos que se focassem em doenças, populações ou etapas da vida específicas; artigos que avaliassem outras estratégias terapêuticas como terapia cognitiva-comportamental ou intervenções farmacológicas; estudos que não explorassem o efeito da hora do dia do exercício físico no sono em indivíduos com insónia.

Considerando os nove estudos elegíveis para análise aprofundada, observou-se que cinco deles exploraram os efeitos da atividade física no sono de pessoas com dificuldades de sono, em horários diferentes do dia. Os restantes quatro estudos investigaram o efeito da atividade física no sono a uma hora específica. Não se encontrou um padrão consistente de resultados entre os estudos analisados. As investigações divergiram consideravelmente quanto aos métodos aplicados (desenho do estudo, características sociodemográficas da amostra, definição de insónia, avaliação do sono/atividade e horário da atividade física investigado), o que comprometeu as comparações entre os estudos e, consequentemente, as conclusões.

Considerando estes estudos e a diversidade de metodologias utilizadas e resultados obtidos, tornou-se difícil encontrar uma hora do dia específica que deva ser recomendada ou desaconselhada para a prática de exercício físico para melhorar o sono de indivíduos com insónia. Mais estudos são necessários para explorar o efeito da hora do dia da atividade física no sono de indivíduos com insónia.

Palavras-chave

INSÓNIA, ATIVIDADE FÍSICA, SONO, HORA DO DIA

1. Introduction

Physical activity is associated with lower risk of mortality from all causes including cardiovascular disease and cancer[1,2]. The beneficial impact of physical activity on sleep is also well documented in the literature[3,4,5,6] and within different populations, i.e., from mid adolescence to adulthood[7] or in patients with mental disorders[8]. Recent systematic literature reviews also reveal that physical activity has a beneficial effect on sleep in insomnia[9,10,11,12], a prevalent sleep disorder particularly in clinical practice[13], associated with several physical and mental problems (e.g. cardiovascular disease, depression)[14].

Diagnostic Statistical Manual of Mental Disorders 5th edition Text Revision[15] and International Classification of Sleep Disorders 3rd edition[16] define insomnia as a complaint related with dissatisfaction with sleep quantity or quality associated with difficulty initiating and/or maintaining sleep or early-morning awakening. This complaint is usually associated with impairment in social, occupational, educational, academic, behavioural or other relevant areas of daily life. Moreover, the complaints must manifest at least 3 nights per week and be maintained for at least 3 months. Sleep difficulty and daytime distress manifest despite adequate opportunity and circumstances to sleep[15,16].

Prevalence of insomnia disorder, defined in agreement with well-established criteria, is between 6 and 10% of the population, insomnia associated with daytime consequences is reported by 10-15% of people[17] and if acute (transient) insomnia is considered, prevalence rises to as high as 50%[18].

On a chronobiological level, a misalignment of the circadian rhythms leading to phase delays or advances of the sleep-wake cycle might lead to either prolonged sleep onset latency or early morning awakening[18]. Overactivity of the hypothalamic-pituitary-adrenal axis and the autonomic nervous system in insomnia supports the assumption that hyperarousal equally contributes to insomnia[18]. Patients with insomnia often reveal high levels of specific personality traits such as neuroticism and perfectionism[19,20], and experience their life as more stressful, Frequently they use cognitive-emotional processes such as repetitive negative thinking in the form of worry (to cope with anticipated problems) or rumination (to deal with a negative past event)[20]. These factors are likely to increase cognitive-emotional and behavioural arousal impairing sleep of insomniacs[18].

Exercise training, improves fitness, potentiates rewards, contributes to self-regulation, self-efficacy and mental health which, for one hand, contributes to regulate affect decreasing affective reactivity, inhibiting avoidance, modulating arousal and interoceptive awareness and, for another hand, enhancing cognitive control and flexibility by goal setting and self-monitoring, decreasing rumination thoughts, increasing focus, attentional control and contributing to

flexible response patterns[21]. This conceptual model of cognitive-behavioural mechanisms through which exercise can improve mental health could also be used to help explaining how exercise can ameliorate sleep. Exercise could enhance sleep of insomniacs by improving emotional regulation processes and by increasing cognitive control over repetitive thoughts as worry or rumination. In addition, exercise can promote distraction, social interaction, have an anxiolytic and antidepressant effect and increase energy expenditure and body temperature to facilitate sleep for body recuperation[10].

First-line treatment for insomnia is cognitive-behavioural therapy (CBT-I)[13,18]. Although pharmacological treatment has comparable effects, long-term effects are only observed with CBT-I[13]. Physical activity could be an alternative and cost-effective strategy for insomnia prevention and treatment as it can be easily implemented by the individual who is free to choose its intensity, frequency or timing, without adverse side effects[10].

The World Health Organization recommends that adults between 18-64 years old practice 150–300 minutes of moderate-intensity aerobic physical activity per week or 75-150 minutes of vigorous aerobic physical activity per week to obtain good sleep[22]. The study by Vancamppfort et al (2018)[23] found out that if WHO[22] recommendations are not followed, the likelihood of experiencing sleep problems increase despite of individuals' socio-demographic characteristics, obesity, chronic physical conditions, depression or anxiety. In fact, the practice of regular physical activity is a common sleep hygiene recommendation for promoting public health[24].

However, it is not completely evident in the literature whether a specific time of day (morning vs. evening) is more advisable (or should be avoided) for exercising to improve sleep, particularly in insomniacs. It would be expected that insomniacs with difficulties initiating sleep as the main insomnia symptom complaint would benefit from morning exercise (and morning bright light exposure) as it is likely to promote a phase advance of circadian rhythms[25] including the sleep-wake cycle; insomniacs with initial insomnia (waking up too early) as the main insomnia sleep complaint would probably benefit from evening exercise (and bright light exposure in the evening) as it will be likely to promote a phase delay of circadian rhythms and possibly of the sleep-wake cycle timings[25]. Alternatively, Gubelman et al. (2018)[26] observed that evening chronotypes are less prevalent among people with high physical activity, than among low physical activity people, which suggests that the phase advance effect may be present regardless of time-of-day of physical activity, although it may also be that evening chronotypes are less likely to exercise more. However, only a few studies as the ones by Passos et al. (2011)[27] or Morita et al. (2017)[28] explored the time-of-day effect of exercise on sleep of insomniacs.

Moreover, it is not clear if exercise ending before bedtime impairs sleep. Stutz et al. (2019)[29] observed that sleep parameters as sleep onset latency, sleep efficiency and total sleep time were impaired when vigorous exercise ended 1 hour or less before bedtime, whereas Frimpong et al. (2021)[30] in a more recent literature review and meta-analysis observed that high intensity exercise 2-4 hours before bedtime did not jeopardized sleep of adults. Youngstetd et al. (2021)[31] in a novel study observed that nighttime exercise did not ameliorate nor disturbed sleep in insomnia patients, yet sleep was severely impaired in two patients. Thus, interpersonal differences may exist when exploring the effect of nighttime exercise on sleep of insomniacs[31]. The effect of nighttime exercise on sleep may also depend on which type of exercise is performed and its intensity[11] as well as if it is acute or regular exercise[30].

Therefore, the main aim of the present study was to verify whether a time-of-day effect exists when exploring the impact of physical activity on insomnia.

2. Methods

To select eligible studies for our study the PRISMA (Preferred reporting items for systematic reviews and meta-analyses) methodology was followed (Figure 1).

A systematic literature search was performed using PubMed electronic database. The terms “Physical Activity” and “Insomnia” were entered in the search engine and the following filters were selected:

1. Text Availability: Full Text;
2. Species: Humans;
3. Language: English, French and Portuguese;
4. Age: Adult (19-44 years) and middle aged (45-64 years);
5. Publication date (custom range): start 2000/1/1 end 2022/3/11.

When the term “Time-of-day” was added to the search engine, along with the other terms referred previously, a very restrictive list of articles emerged compromising our study. Therefore, the term “Time-of-day” was not included in our PubMed search.

A total of 562 articles were identified and were then filtered according to title and abstract. Abstracts not referring insomnia or physical activity, focusing on specific diseases, populations or life stages, such as post-menopausal women, targeting other therapeutic strategies such as

cognitive-behavioural therapy or pharmacological interventions were not considered (n=537). As a result, twenty-five studies were selected to be further explored (Figure 1).

Full texts of these twenty-five articles were inspected in more detail to check the inclusion criteria previously defined and to verify if studies effectively analysed the time-of-day effect of physical activity on sleep of individuals with insomnia. For example, we observed that two studies included participants over 64 years of age, another study compared different types of physical activity regardless of time of day and other studies did not explore time-of-day effect of physical activity on sleep. Therefore, as a result, only 9 articles were considered eligible for our study and to be further analysed.

In resume, inclusion and exclusion criteria for eligible articles for our study were as follows:

1. Inclusion criteria: full text journal articles written in English, French and Portuguese published between 2000 and March 2022 with samples of adults or middle-aged participants (19-44 years and 45-64 years);
2. Exclusion criteria: articles with abstracts that did not refer insomnia or physical activity, studies focusing on specific diseases, populations or life stages, articles evaluating other therapeutic strategies such cognitive-behavioural therapy or pharmacological interventions, studies not exploring the time-of day effect of physical activity on sleep of individuals with insomnia.

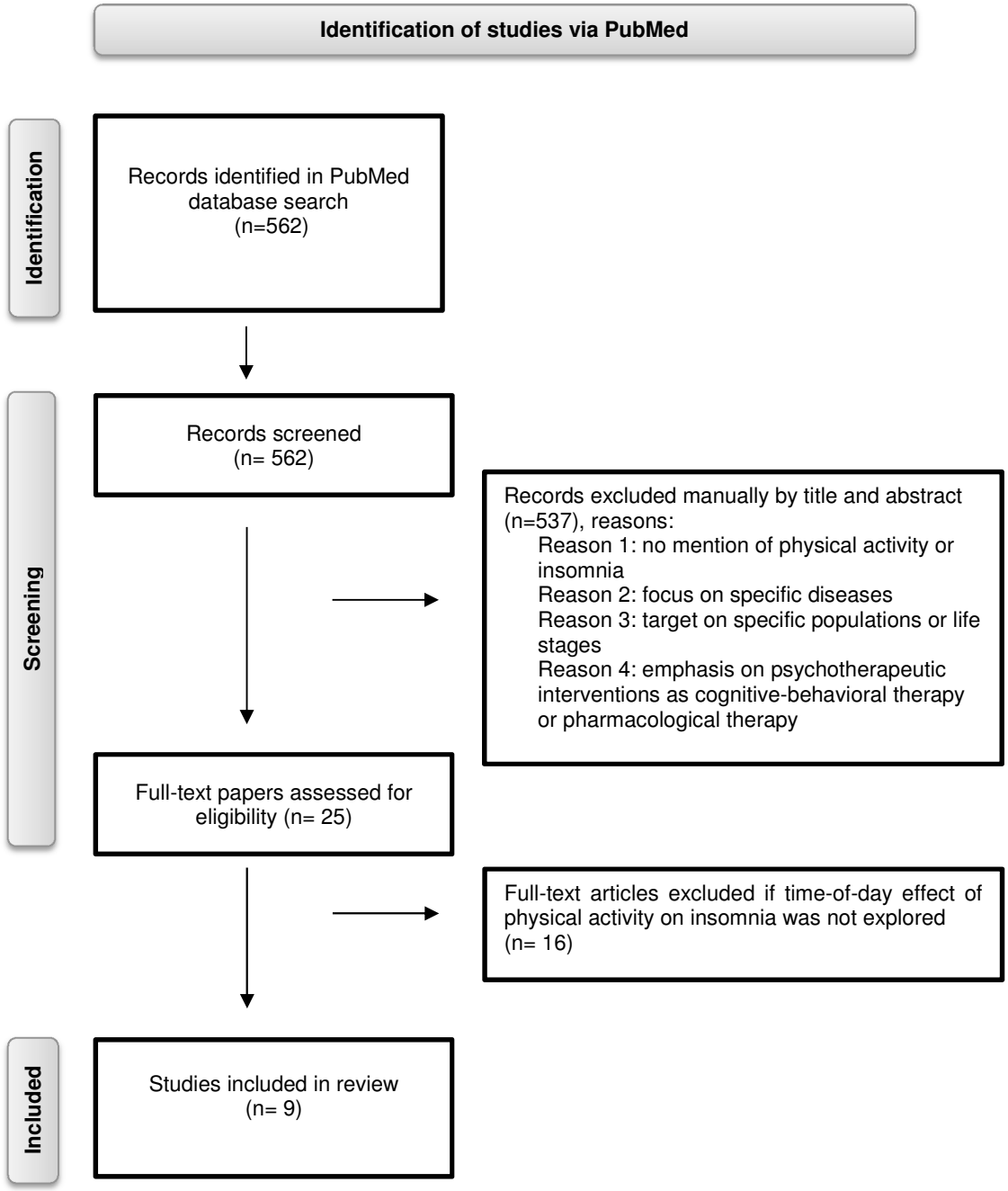

Figure 1: PRISMA 2020 flow diagram for systematic reviews[32].

3. **Results** (see tables 1-7)

Considering the nine eligible studies selected for further analysis, it was observed that five studies (Tworoger et al., 2003[33]; Passos et al., 2011[27]; Morita et al., 2017[28]; Matsangas et al.[34], 2020 and McGovney et al., 2020[35]) explored the effects of physical activity on sleep of individuals experiencing sleep difficulties at different schedules.

Passos et al. (2011) studied 19 individuals who were diagnosed with chronic primary insomnia according to DSM-IV[36]. Subjects were divided in two groups: one group with 10 subjects who performed morning exercise (10:00 a.m.) for 6 months and another group who, for the same duration, performed physical activity in the afternoon (06:00 p.m.). The intervention included 50 minutes of aerobic exercise using a treadmill 3 days a week. Quality of life and mood states were equally evaluated. Polysomnography measurements were taken 48 and 96 hours after completing the exercise training. No significant differences in sleep, quality of life or mood states were found between morning and afternoon exercise, although both regimens had positive effects on sleep-onset, sleep quality and sleep efficiency. In addition, certain quality-of-life measures improved whereas a significant decrease in tension-anxiety and depression mood states was observed[27].

Morita et al. (2017) explored the effects of morning or evening exercise in nocturnal sleep (first half versus second half of the night) of individuals with difficulty initiating sleep (DIS, n= 12) or with early-morning awakening complaints (EMA, n= 15). A group of individuals without insomnia complaints and with a total score of less than 6 in the Athens Insomnia Scale[37] was used as control (n= 13). The physical activity intervention was in a group setting and comprised of 4 sets of 10-minute aerobic step exercise with 5 minutes rest between sets. Both DIS and EMA groups were divided in a morning exercise condition (09:30-11:00 a.m.) or in an evening exercise condition (05:30-7:00 p.m.). One half of DIS group performed a first session of morning exercise and 2 weeks after a second session of evening exercise. The other half of DIS group did the opposite. The same procedure was followed for EMA group. Polysomnographic (PSG) recordings were performed after morning and evening exercise sessions. Acute morning exercise was associated with decreased PSG arousal index for both DIS and EMA groups in the second half of the night. However, no major improvement was verified in either subjective sleep measures or other objective sleep measures (sleep efficiency, wake after sleep onset, sleep onset latency or total sleep time)[28].

Tworoger et al. (2003) investigated the effects of a moderate-intensity exercise or a stretching intervention and its amount and timing on self-reported sleep of 173 women. For this purpose, the group was divided in two sub-groups: an exercise group (n= 87) and a stretching group (n= 86). The exercise group performed daily 45-min moderate-intensity aerobic exercise

(10:30-12:00 a.m. or 06:00-07:30 p.m.) and the stretching group did 4 low-intensity stretching and relaxation sessions (between 10:00-11:00 a.m. or 06:15-07:15 p.m.). The authors observed that among individuals who exercised in the morning, those who exercised more than 225 minutes per week had less trouble falling asleep than those who performed less than 180 minutes of exercise. In contrast, among evening exercisers, those who performed over 225 weekly minutes per week had more trouble falling asleep than those who exercised less than 180 minutes a week. The authors suggested that the effect of moderate-intensity exercise may depend on both the amount of exercise and the time of day it is performed[33].

Matsangas et al. (2020) evaluated whether sleep-related difficulties and behavioural patterns of active-duty service members (N= 1169) were associated with time-of-day exercise routine: early morning, afternoon, evening, late evening or night. The authors performed a regression analysis and observed that workout late in evening/night was one of the predictive factors for sleep difficulties in this population[34].

The study of McGovney et al. (2020) investigated if afternoon and evening activity were associated with sleep difficulties in 160 adults with fibromyalgia and insomnia complaints. Patients used an actigraph on their non-dominant wrist to monitor their activity patterns and three different times of day were analysed: afternoon (12:00-03:00 p.m.), early evening (03:00-06-00 p.m.) and late evening (06:00-9:00 p.m.). The authors observed that afternoon and early evening activity were associated with lower sleep efficiency, lower total sleep time and longer wake after sleep onset. By contrast, late evening activity was not associated with disturbed sleep[35].

The next four studies investigated the effect of physical activity at a specific time of day on sleep (Alparslan et al.,2016[38]; Huang et al., 2016[39]; Stanton et al., 2016[40] and Youngstedt et al., 2021[31]).

Stanton et al. (2016) investigated if morning exercise (8:30 a.m.) improved sleep quality of 40 mental-health patients. Authors observed a significant correlation between post-exercise exertion (after combined aerobic and strengthening exercises at self-selected intensity) and poor sleep quality[40].

Huang at al. (2016) explored the effects of treadmill brisk walking exercise for 30 minutes in two days between 5:30 - 7:30 p.m., during which music was played to maintain the walking tempo and speed. This exercise improved objective and subjective sleep measures. In this study, another intervention with soothing music at bedtime had similar effects[39].

Finally, the studies of Youngstedt et. al (2021) and Alparslan et al (2016) explored the effects of late night exercise on sleep[31,38]. In the study of Youngstedt et al. (2021), participants performed one session of 30 minutes of treadmill exercise and 15 minutes of moderate resistance exercise 2 hours before bedtime. No improvements nor sleep impairment was

observed, although two subjects experienced marked sleep disturbances[31]. The study by Alparslan et al. (2016) investigated the effect of a relaxation exercise, 30 minutes before bedtime, every day, for one week, in 282 hospitalized patients and observed greater sleep quality improvement[38].

With respect to participants gender, it was observed that participants from our 9 eligible studies were: only women in the study of Tworoger et al. (2003)[33], predominantly women in the studies of Passos et al. (2011); Huang et al. (2016) and McGovney et. al. (2020)[27,35,39], mainly men in the study of Matsangas et al. (2020)[34] and gender was equivalent in the studies by Alparslan et al. (2016), Morita et al. (2017) and Youngstedt et al. (2021)[28,31,38]. Stanton et al. (2016) did not mention participants gender[40].

In relation to participants age, most studies included middle aged participants[27,28,33,35,38-40], whereas two studies focused on young adults[31,34].

Various design studies were explored: randomized controlled trials[27,31,33,39], non-randomized crossover study with repeated measures[28], interventional study[38], cross-sectional[35], survey[34] and pilot study[40].

Relatively to insomnia definition, only the studies of Passos et al. (2011) and Youngstedt et al. (2021) followed diagnostic criteria for insomnia according to DSM-IV[36] or ICSD-2[41], respectively[27,31]. The studies of Alparslan et al. (2016), Huang et al. (2016) and Morita et. al. (2017) used a specific cut-off point of the total score obtained with well-known questionnaires for insomnia assessment[28,38,39] as the Pittsburgh Sleep Quality Index[42] or the Athens insomnia Scale[37]. The other studies used self-reported measures of sleep difficulties[34,35] or other sleep questionnaires[33,40].

Physical activity involved treadmill exercise in the studies by Passos et al. (2011), Huang et al. (2016), Stanton et al. (2016) and Youngstedt et al. (2021)[27,31,39,40]. Other studies used aerobic exercise[28], combined aerobic or stretching exercises[31,40], relaxation exercises[38], self-reported exercise routine[34] or movements recorded with an actiwatch strapped on the non-dominant wrist[35].

Objective sleep was evaluated in the studies by Passos et al. (2011), Morita et al. (2017) and Youngstedt et al. (2021) using PSG[27,28,31]; in the study of Huang et al. (2016) with Electroencephalogram (EEG)[39] and in the study of McGovney et al. (2020) through actigraphy[35]. The other studies used self-reported measures of sleep[33,34,3840].

Table 1: Resume of eligible articles of our systematic literature review on physical activity, time-of-day and insomnia

Authors	Aim	Participants	Design	Insomnia	Physical Activity	Other Variables	Time-of-day	Results
Youngstedt et al., 2021	To investigate the effect of nighttime exercise on sleep impairments in individuals with insomnia	N= 12 sedentary adults with insomnia 50% female M= 27.0 ± 2.0 yrs.	Randomized Controlled Trail with counterbalanced design in laboratory. Participants completed 2 treatments (separated by 2-5 days) in counterbalanced order: (1) 30 min of moderate treadmill exercise (60-70% maximum heart rate) + 15 min of moderate resistance exercise and (2) a control treatment (reading).	Chronic insomnia diagnosis based on a physician interview and ICSD-2 criteria.	Treadmill exercise (60-70% maximum heart rate) + 15 min of moderate resistance exercise	PSG Subjective sleep on awakening: SoL TST, time awake and sleep quality State anxiety (STAI) Body temperature	2 hours before bedtime	Late night exercise did not improve or impaired sleep. Marked sleep disturbance in two participants. Authors suggest caution to late night exercise within subjects with insomnia.

Note – M= Mean; yrs.: years; ±: Standard deviation; min: Minutes; PSG: Polysomnography; ICSD-2: International classification of sleep disorders 2nd edition[41]; SoL: Sleel onset latency, TST: Total sleep time; STAI: Spielberger State Trait Anxiety Inventory[43]

Table 2: Resume of eligible articles of our systematic literature review on physical activity, time-of-day and insomnia

Authors	Aim	Participants	Design	Insomnia	Physical Activity	Other Variables	Time-of-day	Results
McGovney et al.2020	To examine if afternoon and evening activity and pain were associated with sleep in patients with fibromyalgia and insomnia complaints	N=160 Adults with FM and insomnia 94% female M=52 ± 12 yrs., range: 18-77 yrs.	Cross-sectional	Self-reported Insomnia complaints: a) > 30 min of SoL or WASO for at least 3 days/week for a duration of 6 months or greater; b) self-reported daytime dysfunction due to insomnia	Participants activity was monitored for 14 days with a wristwatch (Actiwatch-2, Phillips Respironics, Bend, OR, USA)	Pain and medication use.	Wrist activity/movement explored at 3 different times of the day: 12:00-03:00 pm: afternoon activity 03:00-06:00 pm: early evening activity 06:00-09:00 pm: late evening activity	Afternoon activity and early evening activity were associated with lower SE, lower TST and longer WASO. The association between afternoon activity and early evening activity with lower SE is stronger in individuals with higher pain. Late evening activity was not associated with disturbed sleep.
Matsangas et al., 2020	To evaluate sleep-related difficulties and behavioural patterns of ADSMs.	N= 1.169 ADSMs 93.3% male M= 24.7 ± 3.43 yrs., range: 20–44 yrs.	Survey	Sleep-related difficulties: trouble staying asleep, oversleeping, falling asleep while on duty, disturbing dreams, sleep paralysis	Self-reported exercise routine	Sleep-related habits, sleep-related products, sleep aids and techniques, occupational environment, demographic Information.	Exercise routine time-of-day: early morning, afternoon, evening, late evening or night.	Regression model for occurrence of sleep-related difficulties was statistically significant, with workout late in late evening/night being one of 13 predictive factors statistically significant.

Note - M= Mean; yrs.: years; ±: Standard deviation; min: Minutes; FM: Fibromyalgia; ADSMs: Active-duty service members; SoL: Sleep onset latency; WASO: wake after sleep onset; SE: Sleep efficiency, TST: Total sleep time.

Table 3: Resume of eligible articles of our systematic literature review on physical activity, time-of-day and insomnia

Authors	Aim	Participants	Design	Insomnia	Physical Activity	Other Variables	Time-of-day	Results
Morita et al. 2017	To compare the effects of acute morning or evening exercise on nocturnal sleep (first *vs.* second half of the night) of individuals with difficulty initiating sleep (DIS) or early morning awakening complaints (EMA)	N= 40 individuals Control group: n=13, 53.9% female, M=58.8 ± 2.9 yrs. DIS group: n=12, 66.7% female M=58.9 ± 3.6 yrs. EMA group: n= 15, 66.7% female, M=57.7 ± 2.9 yrs.	Non-randomized crossover study with repeated measures	Score 6 or higher on Athens Insomnia Scale, AIS. DIS group: SoL > 30 min 3x week + answer to final awakening AIS subscale of "not earlier" or "a little earlier" EMA group: answer to final awakening AIS subscale of "marked earlier", "much earlier" or "did not sleep at all". Control group: AIS cores <6	4 sets of 10-min aerobic step exercise with 5 min rest between sets in a group setting environment.	BMI PSG AHI PLMI SBP DSP ESS	Morning exercise condition from 09:30-11:00 a.m. Evening exercise condition from 05:30-07:00 p.m.	Morning or evening exercise did not improve subjective sleep. Morning exercise decreased the PSG arousal index in the second half of the night in DIS and EMA groups.

Note - *vs.*= versus; M= Mean; yrs.: years; ±: Standard deviation; min: Minutes; DIS: Difficulty initiating sleep; EMA: Early morning awakening; AIS: Athens Insomnia Scale[37]; SoL: Sleep onset latency; BMI: Body mass index; PSG: Polysomnography, AHI: Apnea-hypopnea index; PLMI: Periodic limb movements index; SBP: Systolic blood pressure; DBL: Diastolic blood pressure; ESS: Epworth sleepiness scale[44]

Table 4: Resume of eligible articles of our systematic literature review on physical activity, time-of-day and insomnia

Authors	Aim	Participants	Design	Insomnia	Physical Activity	Other Variables	Time-of-day	Results
Huang et al., 2016	To investigate the effect of a soothing music intervention before bedtime and a treadmill brisk walking exercise with music in the evening intervention on sleep quality	N=38 sedentary adults with chronic insomnia 78.9% female M= 56.42 ± 6.35, yrs., range: 50-75 yrs.	Randomized crossover controlled trial	Difficulty initiating or maintaining sleep or nonrestorative sleep associated with impaired daytime functioning for at least 1 week assessed with visual analogue scales. PSQI for eligibility for participation in the study (total score >5).	30-min. session of treadmill walking combined with music for 2 days	Anxiety Objective sleep (EEG)	Treadmill walking exercise was performed between 5:30 and 7:30 pm	Both brisk walking with music in the evening and soothing music at bedtimes interventions improved objective and subjective sleep.

Note - M= Mean; yrs.: years; ±: Standard deviation; min: Minutes; PSQI: Pittsburgh Sleep Quality Index (Buysse et al., 1989); EEG: Electroencephalogram.

Table 5: Resume of eligible articles of our systematic literature review on physical activity, time-of-day and insomnia

Authors	Aim	Participants	Design	Insomnia	Physical Activity	Other Variables	Time-of-day	Results
Alparslan et al., 2016	To evaluate the effect of relaxation exercise on sleep quality of hospitalized patients in internal medicine services	N = 282 hospitalized patients in internal medicine services 52.1% female M= 53.67 ± 14.86 yrs. <u>Control group</u>: n= 47 patients not involved in exercise intervention 40.4% female <u>Intervention group</u>: n= 235 patients 45.4% female	Interventional study	PSQI > 5: individuals with poor quality of sleep PSQI < 5: patients with good quality of sleep	Jacobson progressive muscle relaxation technique (PMR). A relaxation exercise brochure showing how to execute the progressive muscle relaxation exercise was given to subjects	Sociodemographic characteristics Individual medical features as obesity, hypertension, chronic disease, gastrointestinal or cardiovascular disease.	Patients performed relaxation techniques for 30 min. before bedtime every day for 1 week	Patients who performed the PMR technique experienced greater sleep quality improvement
Stanton et al. 2016	To investigate if morning exercise improved sleep quality	N|= 40 mental health inpatients M= 45.1 ± 13.8 14 yrs,	Pilot study	RCSQ questionnaire: self-report instrument to evaluate sleep depth, sleep latency, awakings, time to return to sleep and sleep quality.	Combined aerobic exercise (20 min treadmill exercise at moderate pace) and strengthening exercise (20 min. bodyweight or resistance band exercises) at self-selected intensity.	Perceived exertion effort before and after exercise.	Morning (08:30 a.m.)	A significant correlation was observed between increased post-exercise exertion and poor sleep quality.

Note - M= Mean; yrs.: years; ±: Standard deviation; min: Minutes; PSQI: Pittsburgh Sleep Quality Index[42]; PMR: Progressive muscle relaxation technique; RCSQ: Richard Campbell Sleep Questionnaire[45].

Table 6: Resume of eligible articles of our systematic literature review on physical activity, time-of-day and insomnia

Authors	Aim	Participants	Design	Insomnia	Physical Activity	Other Variables	Time-of-day	Results
Passos et al. 2011	To investigate in individuals with chronic primary insomnia the effect of long-term moderate aerobic exercise on sleep, quality of life and mood; to evaluate if these effects diverged whether exercise was practice in the morning or late afternoon.	N= 19 sedentary individuals with chronic insomnia 78.9% female; M= 45.0 ± 1.9 yrs. Morning exercise group: n=10 80% female; M= 42.3 ± 2.6 yrs. Late-afternoon exercise: n= 9. 77.8% female; M= 48.0 ± 2.5 yrs.	Randomized Controlled Trial (6-month exercise training protocol, randomized to morning and late-afternoon exercise groups)	Clinical diagnosis of insomnia according to DSM-IV	6 months of moderate aerobic exercise on a treadmill 3 days a week for 50 min.	Quality of life Mood states Body Composition Sleep diary PSG	Exercise in the morning around 10:00 a.m. Exercise in the late afternoon around 06:00 p.m.	After exercise intervention, Sol and WASO decreased and SE increased. Sleep diaries revealed improvements in Sol, sleep quality and feeling rested in the morning. Qol improved and tension-anxiety and depression mood states decreased. No significant differences between morning and late-afternoon exercise effects on sleep, QoL and mood states.

Note - M= Mean; yrs.: years; ±: Standard deviation; min: Minutes; DSM-IV: Diagnostic and Statistical Manual of Mental Disorders 4th Edition[36]; PSG: Polysomnography; Sol: Sleep onset latency; WASO: Wake after sleep onset; SE: Sleep efficiency; QoL: Quality of life.

Table 7: Resume of eligible articles of our systematic literature review on physical activity, time-of-day and insomnia

Authors	Aim	Participants	Design	Insomnia	Physical Activity	Other Variables	Time-of-day	Results
Tworoger et al. 2003	To investigate effects of a moderate-intensity exercise or a stretching intervention, and its amount and timing, on self-reported sleep quality	N= 173 postmenopausal, overweight or obese, sedentary women not taking hormone replacement therapy Between 50-75 yrs. Exercise group: n=87, M= 60.7 ± 6.7 yrs. Stretching group: n=86, M= 60.6 ± 6.8 yrs.	Randomized intervention trial.	WHIIRS questionnaire Six items used: 1.Sleep quality 2. use of sleep medications or alcohol to help sleep; 3. sleep duration 4. trouble falling asleep 5. falling asleep during quiet activities 6. napping during the day.	Exercise group: moderate-intensity aerobic exercise 5 times per week 45 min at training facility + 2 sessions at home. Stretching group: low intensity stretching and relaxation session. One session per week during 60 min with a physician. 3 sessions per week of 15-30 min. at home.	BMI Heart-rate Depression Job status Marital status Time spent outdoors	Exercise group: sessions at 10:30-12:00 a.m. or 06:00-7:30 p.m. Stretching group: sessions at 10:00-11:00 a.m. or 06:15-07:15 p.m.	Morning exercisers with at least 225 min. of exercise per week had less trouble falling asleep compared with those who exercised less than 180 min. per week. Evening exercisers who exercised at least 225 min. per week had more trouble falling asleep compared to those who exercised less than 180 min. per week. Effect of moderate-intensity exercise may depend on the amount of exercise and time of day it is performed. Stretchers were less likely to use sleep medication and had trouble falling asleep during the intervention period compared with baseline.

Note - M= Mean; yrs.: years; ±: Standard deviation; min: Minutes; WHIIRS: Women`s health initiative insomnia rating scale[46]; BMI: Body mass index

4. Discussion

In the literature it is becoming more evident that physical activity can improve sleep of insomnia patients[9-12]. However, it is not clear whether there is a time-of-day effect of physical activity on sleep quality of people with insomnia. Therefore, the present literature review aimed to investigate this question. Across the nine studies that were analysed, no reliable pattern of results could be identified. The analysed studies explored different research questions and included diverse methodologies compromising comparisons between studies and, as a result, consistent conclusions/recommendations that could be drawn.

Passos et al. (2011)[27] observed that long-term moderate aerobic exercise performed either in the morning or in the evening improved subjective and objective sleep of people with insomnia. However, the authors did not distinguish if insomnia was mainly associated with DIS or early-morning awakening EMA complaints nor investigated whether these insomnia symptoms complaints decreased when exercise was performed in the morning or in the evening exercise, respectively, as it would be expected[25].

Morita et al. (2017)[28]'s study divided subjects between people with DIS and individuals with EMA and observed that morning exercise was associated with a decrease in the PSG arousal index in the second half of the night in both groups. This result was not robust or convincing considering that the study design included a single-session intervention instead of observing the long-term effects of physical activity. If the intervention was made across several sessions, instead of a single session, more substantial differences might have been observed. In addition, had the authors explored more specifically the effects of morning and evening exercise on initial (first hours of sleep) versus final (last hours of sleep) parts of the night, instead of broader halves, results could have been clearer and more consistent relatively to the time-of-day effect of physical activity in DIS and EMA insomnia complaints.

Tworoger et al. (2003)[33] holds particular significance because, besides the time-of-day of physical activity, the study also explored the intensity and frequency of the training exercise. Authors observed that the effect of exercise on sleep may depend on both the time-of-day and amount of exercise performed. Higher frequency of morning exercise during the week decreased sleep onset latency while higher frequency of evening exercise was associated with more difficulties falling asleep. By contrast, Stanton et al. (2016)[40] revealed that increased post-exercise exertion was associated with poorer sleep quality when exercise was performed in the early morning (08:30 a.m.).

The study by McGovney et al. (2020)[35] used different timeframes for physical activity, distinguishing between afternoon, early and late evening but its findings have some similarities with Tworoger et al. (2003)[33]: it found that early evening and afternoon activity were associated

with lower sleep efficiency, reduction of total sleep time and longer wake after sleep onset. In contrast, late evening activity was not found to be associated with increased sleep disturbance. Notably, though, McGovney et al. (2020) utilized for their study a population of people with fibromyalgia[35], which may be a relevant contributing factor for the observed results, particularly due to the interaction between pain and sleep disturbance. Indeed, in their study, the authors point to the fact that the relation they observed was stronger in individuals with higher pain. Thus, it may not be accurate to translate these results to the general population.

Inversely, Huang et al. (2016) found that early evening (5:30-7:30 p.m.) exercise improved objective and subjective sleep measures[39].

Considering the studies above and their diverging results, it is difficult to ascertain a specific time-of-day that should be recommended or not advisable for practicing physical activity to promote or improve sleep of individuals experiencing insomnia. This observation is in accordance with a recent systematic literature review about the influence of physical activity timing (24-hour day) on health[47]. Based on 35 studies this review concluded that there was no consistent evidence that physical activity at one time of day provided better health benefits than physical activity at a different time of day[47].

When exploring in more detail the effects of late evening or night exercise on sleep of people experiencing insomnia, a similar inconstancy of results was observed as the one noted previously: Matsangas et al. (2020) found that workout in late evening/night was associated with sleep difficulties[34]; Alparslan et al. (2016) observed that relaxation exercise before bedtime improved sleep quality[38] and Youngstedt et al. (2021) did not find that moderate intensity resistance exercise ameliorated or jeopardized sleep quality[31]. This last study is in accordance with a recent literature review which revealed that high intensity exercise performed 2-4 hours before bedtime does not disturb sleep in adults[30]. Nevertheless, more studies are needed to investigate the effect of physical activity near bedtime and to explore if different types of exercise (yoga or running, for example) have distinct impact on sleep of people experiencing insomnia. It could be that relaxing exercises or yoga could contribute to decrease arousal levels which are often high in individuals with insomnia and, consequently, improve their sleep[18].

Taking into consideration the diversity of results obtained, it could be argued that time-of-day of physical activity might not be a determinant factor for sleep quality in people with insomnia. In fact, as observed in the study by Passos et al. (2011) physical activity can have a beneficial effect on subjective and objective sleep of individuals experiencing chronic insomnia regardless of the time of day when exercise was performed (morning or evening)[27]. In this study it was equally found that depression and anxiety mood states decreased while self-reported quality-of-life improved after both physical activity interventions (morning or evening).

Therefore, physical activity may have an anxiolytic or antidepressant effect contributing to sleep improvement in insomniacs[10,27]. Physical activity could also promote distraction and increase social interactions[10] improving emotional regulation processes and increasing cognitive control[21] over repetitive thoughts as rumination which are known to enhance cognitive arousal during sleep and contribute to sleep difficulties experienced by people with insomnia[20].

Another argument for the diversity of results obtained in our review when exploring the time-of day effect of physical activity on sleep of individuals experiencing insomnia could be related with the heterogeneity of selected studies. Indeed, our studies investigated the effect of different times-of-day of physical activity on sleep, used discrepant study designs, included divergent methodologies for sleep and activity assessment, applied varied insomnia definitions and included participants with different sociodemographic characteristics. Given these factors, one is led to think that it becomes difficult side-to-side comparisons between studies and to evaluate with confidence whether there is an optimal time, or which times hold the least beneficial results, for observing the expected beneficial effects of physical activity on sleep.

Other limitations of our systematic literature review include the small number of studies found about our research question and the fact that PubMed was the only database selected to perform our literature review, despite being the most widely used and reliable database for medical research.

Nevertheless, to our knowledge, the present systematic literature review is the first to attempt to investigate the time-of-day effect of physical activity on sleep of people with insomnia. In addition, our study opens new directions for research. It would be interesting to explore in the future whether long-term morning, afternoon, or evening exercise have a different impact on specific insomnia complaints (difficulty initiating sleep and early-morning awakening). Another important aspect to include in future studies would be a more precise description of the selected exercise considered (its intensity, frequency, type of exercise) and whether physical activity is performed in a group session, individually or with a monitor, if the exercise occurs outdoors or in gym facilities or if it is considered leisure, occupational or household activity. Subjective and objective measures of sleep and activity would be desirable and insomnia definition could follow the most recent diagnostic criteria for insomnia disorder by DSM-5-TR[15] and ICSD-3[16]. Both laboratory and field studies are equally required. Personality traits often associated with insomnia as neuroticism, perfectionism, hyperarousability, chronotype (morningness or eveningness) could also be evaluated as well as measures of anxiety and depression symptoms.

In conclusion, considering the few studies investigated in our systematic literature review and the discrepancy of methodologies adopted within studies and results obtained, it is not possible

to determine with certainty whether there is an exact time of day to perform exercise to have optimal impact on sleep quality, or if there are certain times of day that should be avoided. Further studies are needed to explore the time-of-day effect of physical activity on sleep of people experiencing insomnia.

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