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REVIEW

Alternative Strategies for Managing Insomnia: The Case of Physical Exercise and Transcranial Direct Current Stimulation. A Narrative Review

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Abstract
The sleep–wake cycle is a process regulated by multiple neurobiological mechanisms that in aberrant functioning provokes several sleep disturbances. Among the major categories of sleep disorders, insomnia represents one of the most reported in population. Pharmacological interventions aimed for treating this sleep disturbance include compounds such as antidepressants, antihistamines, sedative-hypnotics, among others. However, using pharmacological treatments increase undesirable side effects such as addiction to sleep-inducing drugs. Here, we review and summarize recent publications available in PubMed regarding the use of non-pharmacological/invasive means to control insomnia, including physical exercise and transcranial direct current stimulation (tDCS). Current data suggest that these two strategies efficiently manage insomnia, and in turn opens new approaches to develop therapeutical tools to diminish this pathology. Nevertheless, additional research is required to understand the neurobiological mechanism of action of physical exercise and tDCS in insomnia control.

Keywords Insomnia · Physical exercise · Sleep · Stimulation · Population

1 Insomnia

The sleep–wake cycle displays abnormal features characterized and classified in multiple sleep disturbances. In this regard, the International Classification of the Sleep Disorders defines insomnia as a pathology characterized by difficulties in either initiating or maintaining sleep, waking up across the night or earlier than desired in the morning [1]. Epidemiological studies have reported that insomnia is one of the most sleep disturbances in population [2]. Despite that

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different pharmacological treatments have been developed for managing insomnia, including benzodiazepines, benzodiazepine-receptor agonists, etc. [3–6], further side effects are often reported. Here, we review and summarize recent findings available in PubMed regarding the positive effects of using non-pharmacological/invasive means for managing insomnia, including physical exercise and transcranial direct current stimulation (tDCS).

2 Non-pharmacological Interventions for Managing Insomnia

Several reports have suggested that cognitive-behavioral therapy (CBT), mind–body therapies (such as yoga), light therapy, acupressure, physical exercise, tDCS, among others are becoming emerging/non-pharmacological options for managing insomnia [7–13]. In the following sections, we present a general overview of some recent publications regarding the uses of physical exercise and tDCS to control insomnia. In-depth examination of the use of less well-supported approaches (CBT, yoga, light therapy, acupressure, among others) is beyond the scope of this review.

2.1 Physical Exercise

Based in definition of insomnia, several approaches—including physical exercise—have been suggested for managing this sleep disorder. For instance, Crönlein [14] states that further research should define a standardized definition of sleep quality and use this definition to determine the effects of exercise and other interventions. Whether a standard definition of sleep quality is available, several studies have examined the effects of physical exercise in insomnia [15–18]. In this regard, older subjects (55–65 years old) diagnosed with insomnia participated in physical exercise conditions (morning exercise). Under these circumstances, morning exercise diminished the insomnia by decreasing the number of sleep state transitions over the night. Similar results were observed on self-reported quality of sleep, by describing that individuals with a high fitness level, which was associated with regular physical activity and exercise, perceived higher sleep quality. In contrast, participants with a self-reported lack of physical activity evaluated their sleep quality as poor [17]. In line with this observation, the sleep quality of 5000 women over 10 years showed that subjects that had a higher level of physical activity reported lower risks of developing insomnia [18]. Other studies have indicated that prolonged time of daily physical activity significantly reduced the risk of insomnia [16]. In this regard, Dzierzewski et al. [19] found that moderate to vigorous physical activity influenced the subjective sleep quality.

The resulting effects of physical exercise in insomnia management are thought to be mediated by thermoregulation [20]. Sleep onset is associated with a decline in body temperature, which is increased if physical exercise is applied between 2 and 6 pm. In response, the mechanisms of heat dissipation are activated and sleep is improved. Thus, one would assume that heating the body leads to an improvement of sleep [21, 22].

In addition, a variety of factors that influence the effects of physical exercise in insomnia control, include intensity, type of physical exercise and timing. Several lines of evidence suggest that moderate-intensity physical aerobic exercise in the afternoon using a treadmill [running speed at 4 km/h (3-min warm-up) with increments of 0.5 km/h every minute up to voluntary exhaustion during 50 min], but not after high-intensity physical aerobic exercise (3 periods of 10 min of exercise on a treadmill alternating with 10 min of rest) or moderate resistance physical exercise (shoulder/chest/leg press, vertical traction, leg curl/extension, abdominal crunch, or lower back. Three sets of 10 repetitions with 90-s recovery intervals during 50 min), decreases insomnia [23]. However, contradictory findings are available. For instance, a study compared the effects of acute morning or evening aerobic step physical exercise in two subjective insomnia criteria: difficulty in initiating sleep and early morning awakening. Results showed that acute physical exercise in the morning decreased the difficulties for initiating sleep but subjective sleep quality did not change after the acute interventions [24, 25].

The role of physical exercise in insomnia control might engage functioning of hormones. It has been demonstrate that acute physical exercise is linked with insomnia symptoms via cortisol levels since the contents of this hormone have been found increased after acute high-intensity training [26, 27]. An elevated cortisol levels in the evening correlate with the number of bouts of nocturnal awakenings in insomnia patients [28]. However, chronic moderate aerobic exercise using treadmill with an initial velocity of 4 km/h, increasing speed by 0.5 km/h each minute until voluntary exhaustion (3 times/week/4 months) decreased the cortisol levels, reduced sleep onset latency, and significantly increased total sleep time [29]. Although the mechanisms that underlie the interrelation between physical exercise and hormones functioning remain to be fully characterized, it seems that physical exercise exerts control of insomnia.

An additional variable that influences the effects of physical exercise in insomnia control is the timing of the intervention since early morning awakening seems to be associated with an advanced core body temperature rhythm [30]. Other studies have demonstrated that chronic moderate to high-intensity physical exercise interventions (step aerobics exercise 3 times/week/10 weeks at an intensity of 75–85% of the heart rate reserve during 45 min) modified the circadian rhythm, which is related with melatonin levels of individuals [31]. Opposite findings have been described by showing that low-intensity/chronic physical exercise exerts negative effects on the secretion of melatonin [32]. Despite the current evidence describes the relationship among physical exercise and melatonin release [33, 34], further studies are needed to clarify the mechanism of action that implies the interrelation of these two variables.

Insomnia also has been associated with an impaired immune function, such as lower levels of immune cells [35, 36]. Thus, the relationship between immune system and physical exercise might explain the positive effects of physical exercise in insomnia management. Nehlsen-Cannarella et al. [37] examined the role of moderate physical exercise training on the immune response finding changes in immune system such as immunoglobulins and T-cell subpopulation after 6–15 weeks of training.

On the other hand, moderate aerobic exercise showed positive trends towards increased total sleep time and decreased of awakening during sleep time [38]. In addition, the effects of an aerobic physical exercise in older adults with mild sleep impairments have demonstrated that the 8-week long intervention of 2 aquatic exercise sessions of 60 min/week lead to significant benefits on the sleep onset latency and the sleep efficiency [39]. Similar findings have been reported in this regard. For example, randomized controlled trials with physical exercise training programmes between 10 and 16 weeks, consisting of moderate to vigorous aerobic or resistance training with a dataset of over 300 participants with sleeping problems, showed positive effects on sleep quality as well as a sleep latency reduction [40]. Moreover, Hartescu et al. [41], published the outcomes of a randomized controlled trial in which the insomniac participants were instructed to walk at moderate-intensity for at least 30 min/day/5 days/week over a period of 6 months. The results of this intervention reduced the severity of insomnia symptoms and a significantly elevated mood. Thus, greater insomnia symptoms predict greater improvements in mood state after physical exercise [42].

In overall, the available literature suggests that acute as well as moderate physical exercise controls insomnia [43, 44]. Moreover, it is worthy to mention that long-term moderate-intensity aerobic exercises have shown to be more effective in managing insomnia over a prolonged period of time [23, 45–47].

2.2 Transcranial Direct Current Stimulation for Insomnia

Transcranial direct current stimulation (tDCS) is a non-invasive brain stimulation technique that applies a low-intensity and continuous current that presumably induces cortical excitability changes [48]. tDCS has been used for multiple health purposes [48–53]. Regarding the use of tDCS in insomnia, the role of prefronto-thalamic-cerebellar circuit on cognitive dysfunctions and sleep quality in euthymic bipolar disorder (BD) patients have showed that tDCS (2 mA) for 20 min/day during 3 consecutive weeks applied to left dorsolateral prefrontal cortex (DLPFC) and right cerebellar cortex improved sleep [54]. It has been suggested that DLPFC and cerebellum play a relevant role in modulating sleep [55, 56]. Similar findings were reported by Galbiati et al. [57] since the effects of anodal tDCS applied to left DLPFC on arousal of patients with idiopathic hypersomnia during the 4 weeks/3 times/week reduced excessive daytime sleepiness. These results suggest that tDCS may modulate sleepiness in idiopathic patients [55–57].

Emerging research has demonstrated that application of slow oscillatory tDCS compared to sham-slow oscillatory tDCS decreased waking time [58–60]. These findings suggest a putative sleep-stabilizing role for slow oscillatory after tDCS in insomniacs [61, 62]. Despite the mechanism of action of tDCS in insomnia control remains to be described, it is thought that nitric oxide (NO) might be engaged in the control of insomnia. Recent evidence has shown that release of NO promotes sleep [63]. Following this idea, the gap junction permeability of neurons may be affect by NO, which in turn could activate sleep-related neurons that project to several areas of the central nervous system, including cerebral cortex [64]. Thus, it is suspected that slow oscillatory tDCS would increase NO production leading to sleep promotion. Nevertheless, future studies should be aimed to

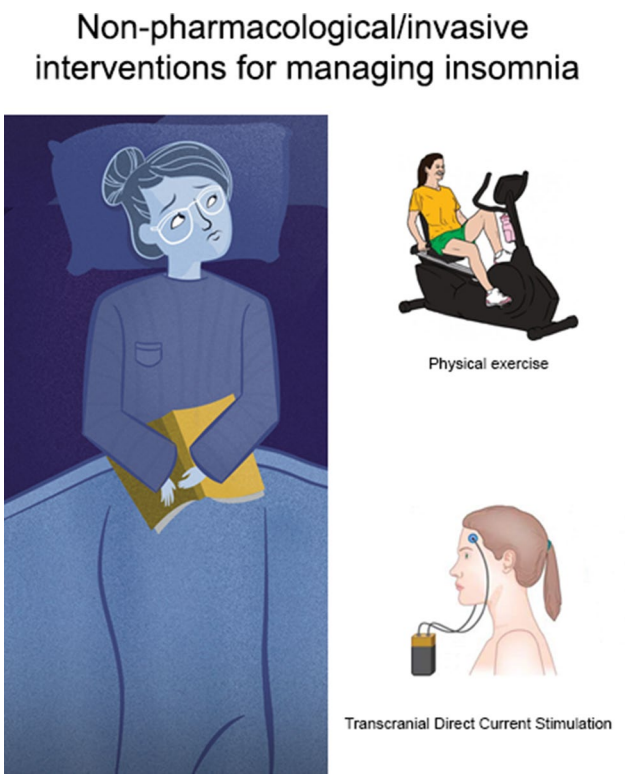

Fig. 1 The use of non-pharmacological/invasive approaches for managing insomnia. Physical exercise and/or transcranial direct current stimulation have shown positive effects for treating insomnia

address this assumption. Besides, wider parameters for tDCS stimulation might be focus of further reports.

3 Conclusions

Insomnia is a sleep disorder reported in general population [1, 2]. Despite the wide spectrum of pharmacological options for treating insomnia [3–6, 65, 66], alternative non-pharmacological/invasive strategies for preventing and managing this sleep disturbance are emerging as an effective therapeutic option, including physical exercise as well as tDCS [7–47, 54–57, 60, 66–68] (Fig. 1).

In this regard, physical exercise controls insomnia in different approaches. For example, subjects with a high fitness level linked with physical activity and exercise, self-perceived higher sleep quality [16, 17]. In addition, moderate-intensity physical aerobic exercise in the afternoon using a treadmill, but not after high-intensity physical aerobic exercise (intense physical exercise in treadmill) or moderate resistance physical exercise (weightlifting), control insomnia [23]. On the other side, the use of tDCS for treating insomnia has limited exploration. Despite that few papers have been published in this regard, common findings have been described: application of tDCS to DLPFC and right cerebellar cortex decreases insomnia [54, 57]. Although the revised evidence suggests that physical exercise and tDCS manages insomnia [7–47, 54–57, 60–68], further studies should be aimed to verify if these two strategies fulfill international guidelines for managing insomnia, including the American Academy of Sleep Medicine or the European Sleep Research Society recommendations [3, 69, 70]. Likewise, as one can assume, timing, duration, and type of physical exercise displays different effectiveness in insomnia control. Same criteria for using tDCS by variables such as time, duration and intensity of stimulation. An additional issue to be addressed is the possible long-term effects of using physical exercise or tDCS in insomnia. Finally, the lack of data describing the mechanism of action of physical exercise or tDCS represents a gray area that needs to be addressed (Table 1).

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Compliance with Ethical Standards

Ethical standards All data reported in this paper are from public repositories.

Conflict of interest Authors declare no conflict of interest.

Table 1 Summary of some positive uses of physical exercise and transcranial direct current stimulation (tDCS) to control insomnia

	Physical exercise	TDC stimulation	References
Insomnia symptoms	Decrease the symptoms of insomnia	Reduce the symptoms of insomnia	[7–48, 55–58, 61, 67–69]
Long-term effects controlling insomnia	Not determined	Not determined	Not available
Neurobiological mechanism of action	Unknown	Unknown	Not available

However, no evidence is available regarding either the long-term effects of controlling insomnia or the neurobiological mechanism of action using physical exercise or tDCS

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