Review Article

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Association of physical activity with sleep health: a systematic review

Associação da atividade física com o sono: uma revisão sistemática

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ABSTRACT

The aim of this study was to systematically examine the literature on physical activity and sleep in non-clinical and population-based settings. The inclusion criteria were original studies testing the association between physical activity (as exposure) and sleep (as outcome) in representative samples of the general population, workers, or undergraduate students. Sleep health included sleep duration, sleep quality and insomnia. Studies evaluating samples including only individuals with some disease or a health condition were excluded. A search was performed in the PubMed, Scopus, Lilacs, CINAHL, and SPORTdiscus databases in March 2018. Data extraction was performed using the following items: year, author, country, population, age group, sample size, study design, sleep measurement/definition, physical activity measurement/definition, adjustment and main results. A total of 57 studies were selected, which markedly used heterogeneous instruments to measure physical activity and sleep. The majority were conducted in high-income countries and with cross-sectional design. Physical activity was associated with lower odds of insomnia (observed in 10 of 17 studies), poor sleep quality (observed in 12 of 19 studies) and long sleep duration (observed in 7 of 11 studies). The results about short sleep or continuous sleep duration remain unclear. Physical activity seems to be associated with sleep quality and insomnia, especially among adult and elderly populations in which these outcomes are more usually measured. The short- and long-term effects of physical activity intensities and dose-response on sleep should be better evaluated.

Keywords: Epidemiology; Sleep; Motor activity.

RESUMO

Examinar sistematicamente a literatura sobre atividade física e sono em amostras não clínicas e de base populacional. Foram incluídos artigos originais testando a associação entre atividade física (como exposição) e sono (como desfecho) em amostras representativas da população em geral, de trabalhadores ou de universitários. Os desfechos incluídos foram duração do sono, qualidade do sono e insônia. Estudos que avaliaram amostras que incluíram somente indivíduos com alguma doença ou condição de saúde foram excluídos. A busca foi realizada em março de 2018 nas seguintes bases: PubMed, Scopus, Lilacs, CINAHL e SPORTdiscus. As informações extraídas dos dados foram ano, autor, país, população, faixa etária, tamanho da amostra, delineamento, mensuração e definição das variáveis de desfecho e exposição, variáveis de ajuste e principais resultados. Foram selecionados 57 estudos. A maioria foi conduzida em países de renda alta e com delineamento tranversal. Atividade física foi associada a menor odds de insônia (10 de 17 estudos), qualidade ruim do sono (12 de 19 estudos) e longa duração (7 de 11 estudos). Os resultados sobre curta duração ou duração avaliada de forma contínua permanecem inconclusivos. Os estudos selecionados usaram instrumentos heterogêneos tanto para atividade física quanto sono. Atividade física parece estar associada com qualidade do sono e insônia especialmente entre adultos e idosos onde estes desfechos foram mais frequentemente avaliados. Os efeitos a curto e longo prazo da atividade física em diferentes intensidades ainda precisam ser melhor explorados em futuros estudos originais.

Palavras-chave: *Epidemiologia; Sono; Atividade motora.*

Introduction

Sleep influences several physiological processes in humans, such as hormonal secretion, energetic balance, and homeostasis[1,2]. Healthy sleep is associated with reduced risk of chronic diseases, work and traffic accidents, mental disorders, and also with better quality of life and academic achievements[1,3-6]. Therefore, sleep health should be considered as an import public health problem due to its association with general health status and organism homeostasis[1], and due the considerable proportion of population affected. In the United States, adults showed a prevalence of 13.5% for short

sleep duration (< 6h)[7], while in Greece, 25.3% of adult population presented insomnia[8].

Several sociodemographic and behavioural factors have been shown to influence sleep-related outcomes. In general, sleep disorders are more frequent among women, older adults, white-collar workers, smokers, those with higher alcohol and caffeine consumption, and obese or overweight individuals[9-13]. The American Academy of Sleep Medicine and Sleep Research Society suggest physical activity as a factor that could help to improve sleep health parameters[14], but evidence at the population level has not yet been clearly identified.

The effects of physical activity on sleep seem to be attributed to body thermoregulation, energy conservation, tissue restoration, hormonal secretion, regulation of the circadian rhythm, and improvement in physical fitness[15,16]. These mechanisms possibly present short- and long-term effects on sleep, but such relationships are difficult to elucidate. A meta-analysis including only experimental studies showed that some effects of physical activity on sleep only exist, or are more pronounced, with a regular frequency of weekly physical activity practice[17].

It is important to highlight the conceptual differences between physical activity and exercise – a regular activity planned to reach specific aims such as maintaining or increasing health or fitness. The research area of physical activity and sleep began with studies evaluating only exercise and found positive effects on sleep outcomes[15,17-19], but these effects remain unclear. In observational studies, temporality is an issue which should be considered in the relationship between physical activity and sleep. Some authors have argued there is a bidirectional effect: a bad night of sleep also influences exercise practice on the next day[20,21].

Most of the literature about the relationship between physical activity and sleep is limited to small experimental studies with volunteers or clinical samples. This limits the generalisation of the results for the entire population, and the pattern of such an association with population levels remains unclear. The effects of overall physical activity (not necessarily structured) also are unknow, since most of literature is based in studies evaluating exercises only. Therefore, this review aims to systematically examine the literature on physical activity and sleep parameters (sleep duration, sleep quality and insomnia) in non-clinical participants from samples with representativeness of a target population. Our hypothesis was that most studies have found a positive relationship between physical activity and sleep health.

Methods

The search was performed in March 2018 in following databases: PubMed, Scopus, Lilacs, CINAHL, and SPORTdiscus. We used keywords related to physical activity ("physical activity" OR "motor activity" OR "exercise" OR "physical inactivity") in combination with terms for sleep duration sleep quality and insomnia ("sleep health" OR "sleep duration" OR "sleep quality" OR "sleep disorders" OR "Pittsburgh Sleep Quality Index" OR "insomnia" OR "polysomnography" OR "actigraphy"). Each database has its specific rules for combining terms and were adjusted to the search accordingly. We opted for these three outcomes after an exploratory search which identified them as the most frequent outcomes in population-based studies of sleep. Furthermore, these outcomes are the most related to general health.

References selection (title and abstract reading) was performed by two independent reviewers simultaneously and in cases of no consensus about inclusion, a third reviewer was required for the final decision. We emailed the authors' manuscript when full text was not available.

The inclusion criteria were original studies testing the association between physical activity (as exposure) and sleep duration, sleep quality or insomnia (as outcomes) in representative samples of general populations, or specifically samples of workers or undergraduate students representing the target population they aimed at. We excluded studies evaluating physical activity and sleep variables as exposures for other health outcomes, convenience/volunteer-based samples, groups of individuals with some disease or health condition (e.g. obesity, insomnia or other sleep disorders, and/or fibromyalgia) or specific populations (e.g. athletes) and studies where effect measures were not reported. We also focused the review on studies with leisure-time physical activity isolated or combined with other domains. There were no exclusion criteria regarding population age and language. Reference lists from selected studies were also checked. The methodological procedures carried out in this review follow the PRISMA guidelines for systematic reviews[22].

Data extraction was performed using the following items: year, author, country, population, age group, sample size, study design, sleep measurement/definition, physical activity measurement/definition, adjust-

ment and main results. Selected studies were evaluated regarding the quality of the report, taking into account (a) response rate report, (b) sleep variable description in text, (c) physical activity variable description in text, (d) adjustment at least for sex/gender, age, and socioeconomic/educational status. We establish this criterion after a discussion about which parameters may capture the quality of studies, since most of the existing scales to measure the quality of studies could not properly be applied in the selected studies.

In order to compare and present the results in a clear way, selected studies were presented as three groups of outcomes: (a) sleep duration, (b) insomnia; and (c) sleep quality. Manuscripts evaluating more than one outcome were included for each outcome. References evaluating more than one dimension of sleep duration (e.g. short and long sleep) were also evaluated separately.

In order to make the results clearer, three categories regarding the association of physical activity with sleep were created:

- Physical activity improves sleep: when physical activity decreases the risk of adverse sleep outcomes (e.g. short sleep, long sleep, insomnia or poor quality) or increased the risk of "good" sleep outcomes (e.g. adequate sleep duration, good sleep quality, and insomnia absence). We also considered as improvement in sleep when physical inactivity or low physical activity increases the risk of "bad" sleep outcomes or decreases the risk of "good" sleep outcomes.
- Physical activity worsens sleep: when physical activity increases the risk of adverse outcomes or decreases the risk of "good" outcomes. Also, it was defined as worsening when physical inactivity or low physical activity decreases the risk of adverse outcomes or increases the risk of "good" outcomes.

Results

The search identified 16,647 references. Figure 1 presents the number of studies included/excluded in each phase of this review. After all processes, 57 studies were included (Figure 1).

Table 1 presents features of the selected studies. From 57 studies, 28 included population-based samples of adults and elderly[7,8,10,13,23-46], among them, seven only elderly[23,25,30,32,33,36,37]. Sixteen studies included

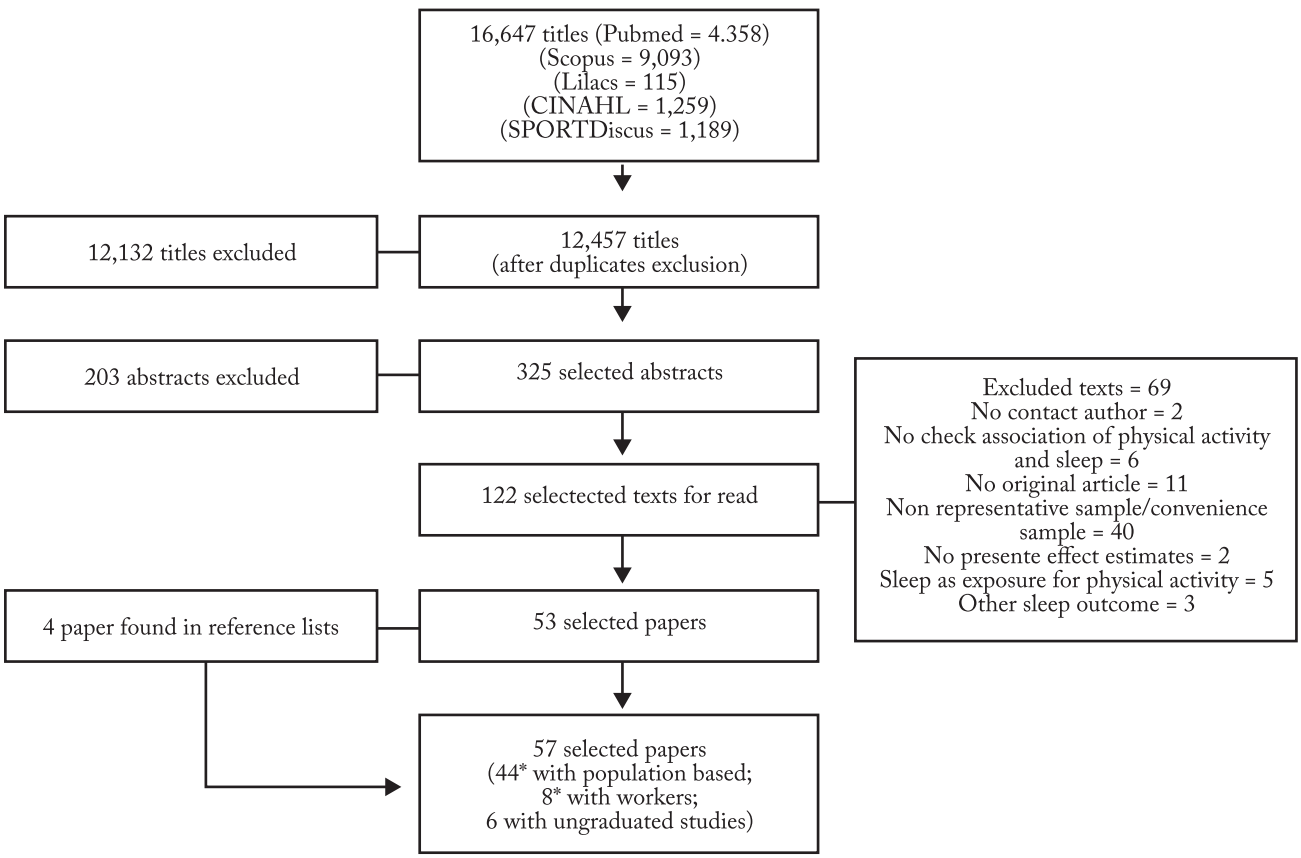

Figure 1 – Flow chart describing the study selection.
*One study had two samples (population-based and workers) and was included two times in the review.

Table 1 – Description of selected studies (n = 57).

Variables	Number of studies (%)	Reference
Outcome		
Sleep duration	28 (49.1)	7, 10, 13, 27, 28, 29, 31, 37, 38, 39, 42, 43, 44, 47, 48, 49, 50, 52, 53, 54, 55, 56, 57, 58, 61, 64, 65, 68
Short sleep	22 (38.6)	7, 10, 13, 27, 28, 29, 37, 38, 39, 42, 43, 44, 47, 48, 52, 53, 56, 57, 58, 54, 64, 65
Long sleep	10 (17.5)	7, 10, 13, 27, 28, 29, 37, 38, 42, 58
Continuous/adequate sleep duration	7 (12.3)	31, 43, 49, 50, 55, 61, 68
Insomnia	17 (29.8)	8, 20, 22, 23, 24, 25, 26, 30, 33, 34, 35, 36, 40, 43, 45, 46, 67
Sleep quality	19 (33.3)	31, 32, 41, 43, 44, 45, 51, 55, 58, 59, 60, 62, 63, 66, 69, 70, 71, 72, 73
Sample		
Children and adolescents	16 (28.1)	22, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61
Adults and the elderly	28 (49.1)	7, 8, 10, 13, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 43, 44, 45, 46
Workers	8 (14.0)	7, 20, 62, 63, 64, 65, 66, 67
Undergraduates	6 (10.5)	68, 69, 70, 71, 72, 73
Study design		
Cross-sectional	45 (78.9)	7, 8, 10, 13, 22, 24, 25, 26, 27, 28, 29, 31, 33, 34, 35, 38, 39, 41, 42, 43, 44, 46, 47, 48, 50, 51, 58, 59, 60, 52, 53, 54, 55, 56, 57, 59, 61, 63, 67, 68, 69, 70, 71, 72, 73
Cohort	12 (21.1)	20, 23, 30, 32, 36, 37, 40, 45, 62, 64, 65, 66
Continent		
America	14 (24.6)	7, 10, 24, 31, 33, 38, 39, 44, 45, 51, 56, 58, 60, 63
Asia	25 (43.9)	13, 22, 25, 28, 29, 30, 32, 37, 41, 42, 46, 48, 52, 53, 55, 57, 62, 64, 65, 66, 68, 69, 70, 71, 72
Europe	18 (0.32)	7, 20, 23, 26, 27, 34, 35, 36, 40, 43, 49, 50, 54, 59, 61, 67, 73
Oceania	1 (0.0)	47
Income classification (World Bank)		
Middle	17 (29.8)	22, 29, 32, 33, 37, 41, 42, 48, 53, 55, 56, 57, 60, 63, 69, 70, 71
High	40 (70.1)	7, 8, 10, 13, 20, 23, 24, 26, 27, 28, 30, 31, 34, 35, 36, 38, 39, 40, 43, 44, 45, 46, 47, 49, 50, 51, 52, 54, 58, 59, 61, 62, 64, 65, 66, 67, 68, 72, 73
Response rate or losses and refusals reported or N for calculations	44 (77.2)	7, 8, 10, 20, 22, 23, 25, 26, 27, 28, 29, 30, 32, 34, 35, 36, 37, 38, 40, 42, 43, 45, 46, 47, 48, 49, 50, 51, 54, 55, 57, 58, 59, 62, 63, 64, 65, 66, 67, 69, 70, 71, 72, 73
Description of sleep measure	57 (100.0)	7, 8, 10, 13, 20, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73
Description of physical activity measure	41 (71.9)	7, 8, 10, 13, 20, 23, 24, 26, 27, 28, 30, 31, 32, 33, 36, 39, 40, 43, 44, 45, 47, 49, 50, 52, 54, 55, 58, 59, 60, 61, 62, 64, 65, 66, 67, 69, 70, 71, 72, 73
Adjusted/stratified to sex, age and socioeconomic status	36 (63.2)	7, 8, 13, 22, 20, 27, 28, 29, 30, 31, 32, 36, 37, 38, 39, 40, 42, 43, 44, 45, 46, 48, 50, 53, 54, 55, 58, 59, 60, 63, 66, 69, 70, 71, 73
Year of publication		
Up to 2000	5 (8.8)	22, 23, 24, 25, 46
2001 to 2010	11 (19.3)	7, 8, 10, 26, 27, 28, 45, 47, 48, 62, 68
2011 to 2015	22 (38.6)	13, 20, 29, 30, 31, 32, 33, 34, 49, 50, 51, 52, 53, 54, 55, 61, 63, 64, 65, 69, 70, 71
2016+	19 (33.3)	35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 56, 57, 58, 59, 60, 66, 67, 72, 73
Sample size		
Up to 600	7 (12.3)	25, 35, 45, 47, 50, 56, 59
601 to 1500	16 (28.1)	8, 22, 23, 24, 31, 32, 33, 36, 58, 60, 61, 62, 67, 68, 70, 72
1500+	34 (59.6)	7, 10, 13, 20, 26, 27, 28, 29, 30, 34, 37, 38, 39, 40, 41, 42, 43, 44, 46, 48, 49, 51, 52, 53, 54, 55, 57, 63, 64, 65, 66, 69, 71, 73

*One study evaluated two samples (one with workers and one of adult population-based).

samples of children and adolescents[22,47-61]. Eight studies assessed workers' samples[7,20,62-67] and six included only undergraduate students[68-73]. More than 60% of studies were published after 2011 and included samples with at least 1,500 individuals.

The majority of the selected studies came from Asia,

especially China (n = 14)[22,29,32,37,41,42,48,53,55,57,69-72]. Around one third of the references (17 out of 57) were studies carried out in middle-income countries according to the World Bank classification, no studies from low-income countries were found. Regarding the study design, 45 were cross-sectional and 12 were cohort studies. The most common outcome evaluated was sleep duration (n = 28; 49.1%). In these studies, 22 (38.6%) evaluated short sleep duration, 10 (17.5%) evaluated long sleep duration and seven (12.3%) evaluated adequate sleep duration or continuous variable. Insomnia was evaluated in 17 (29.8%) and sleep quality in 19 (33.3%) studies.

Around three-quarters of studies (n = 44) reported some response rate or made the original sample size available for such calculation. All studies presented a clear outcome description. Regarding physical activity, sixteen did not provide clear information about the instrument used to measure it[22,25,29,34,35,37,41,42,46,48,51,53,56,57,63,68]. Regarding adjustment, only 63.2% of studies showed adjusted analyses for sex, age, and socioeconomic/educational status (Table 1). Detailed information about each study may be found in Supplementary Table.

Figure 2 shows the results found in this review. Physical activity seems to present a positive effect in long duration of sleep, insomnia and sleep quality, while the possible effect in short and continuous duration of sleep remains unclear.

Figure 3 summarizes the results of the association between physical activity and sleep duration according to some study characteristics. Short sleep duration was assessed in 22 studies[7,10,13,27-29,37-39,42-44,47,48,52-54,56-58,64,65]. The majority of the studies (n = 13) did not show any association[7,10,13,27,37,39,43,44,47,48,56,58,65]. Long sleep duration was assessed in 11 studies. The majority of studies (n = 7) showed that physical activity decreases long sleep duration[7,10,13,29,37,38,42], and four of them did not find any association[7,27,28,58]. Seven studies evaluated continuous or adequate sleep duration, from which four did not find any association[31,49,61,68].

The effects of physical activity on insomnia or difficulty initiating/maintaining sleep are presented in Figure 4 (n = 17). All the studies used questionnaires to measure sleep and two used accelerometers to measure physical activity, one of them in adult population-based sample[43] and another with workers' sample[67]. Regarding the association tested, 10 studies found that physical activity reduces odds/incidence of insomnia[8,22-24,26,30,34,35,40,46] and seven did not find any association[20,25,33,36,43,45,67].

All of the 19 studies that evaluated sleep quality (Figure 4) used questionnaires to measure sleep quality. The most common was the Pittsburgh Sleep quality Index (PSQI), which was used in 13 studies[32,41,43,45,51,58,59,62,69-73]. Only one study measured physical activity using accelerometers[43]. Twelve studies showed physical activity improves sleep quality[31,32,41,51,59,62,63,66,69-71,73] and in seven no association was found[43-45,55,58,60,72].

For all outcomes, the patterns of association among the studies with and without adequate adjustment for potential confounders were similar.

Discussion

This review presented a summary of studies assessing the association between physical activity and sleep duration, sleep quality and insomnia in population-based

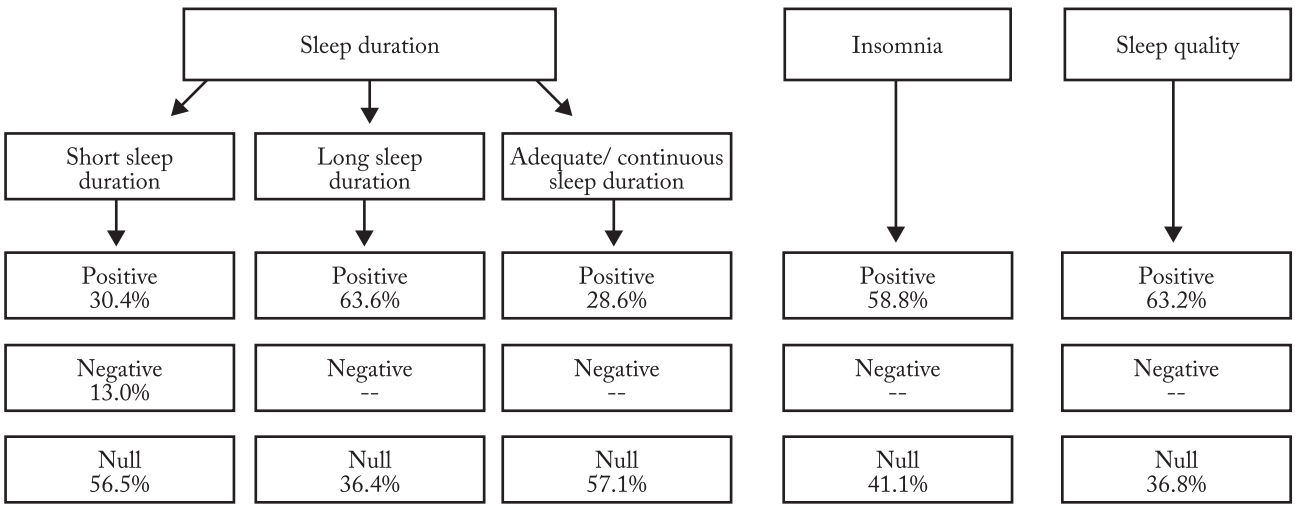

Figure 2 – Summarized results of review.
*Population-based samples. One study used accelerometer and questionnaire to measure physical activity.

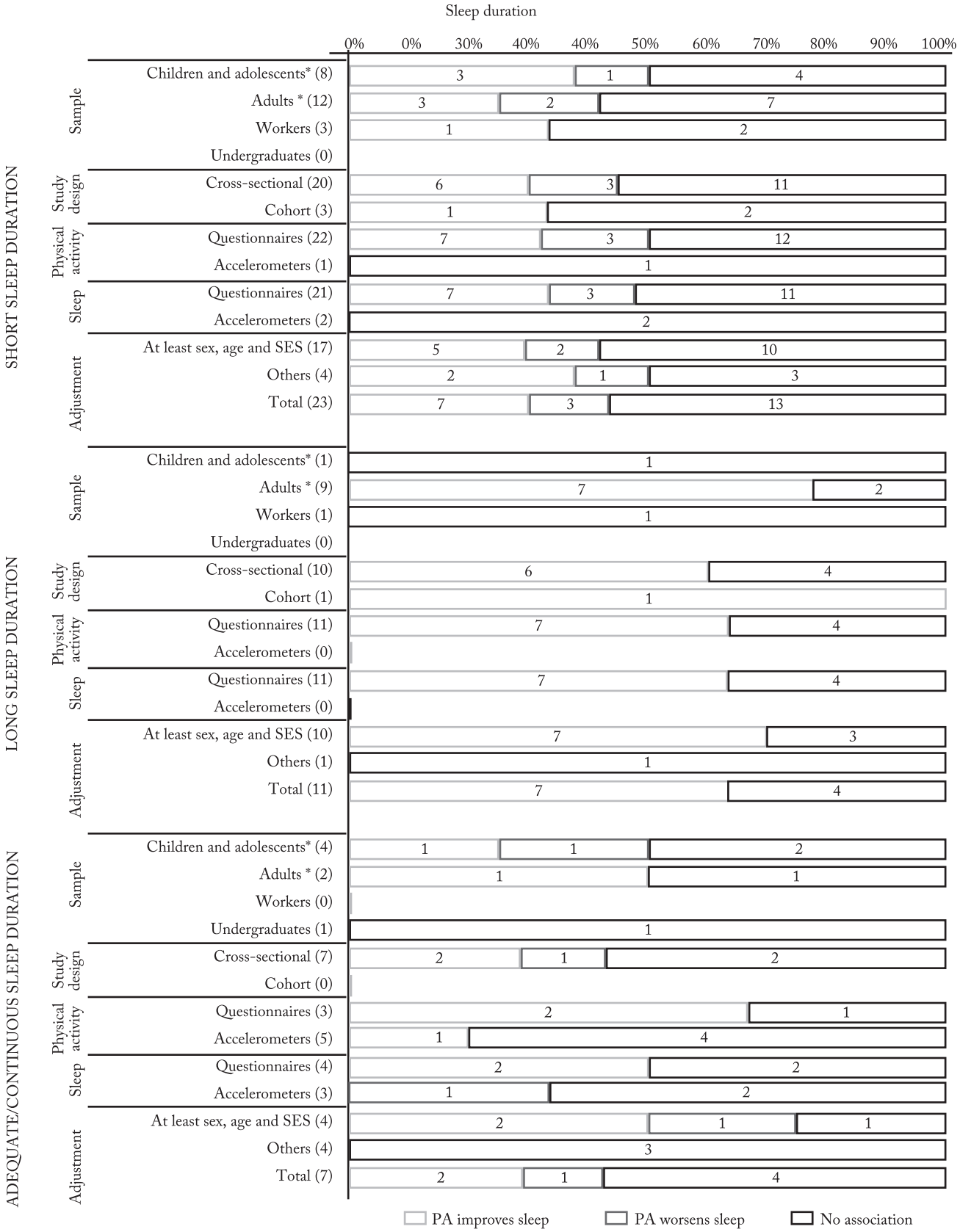

Figure 3 – Effects of physical activity on sleep duration according to study characteristics.

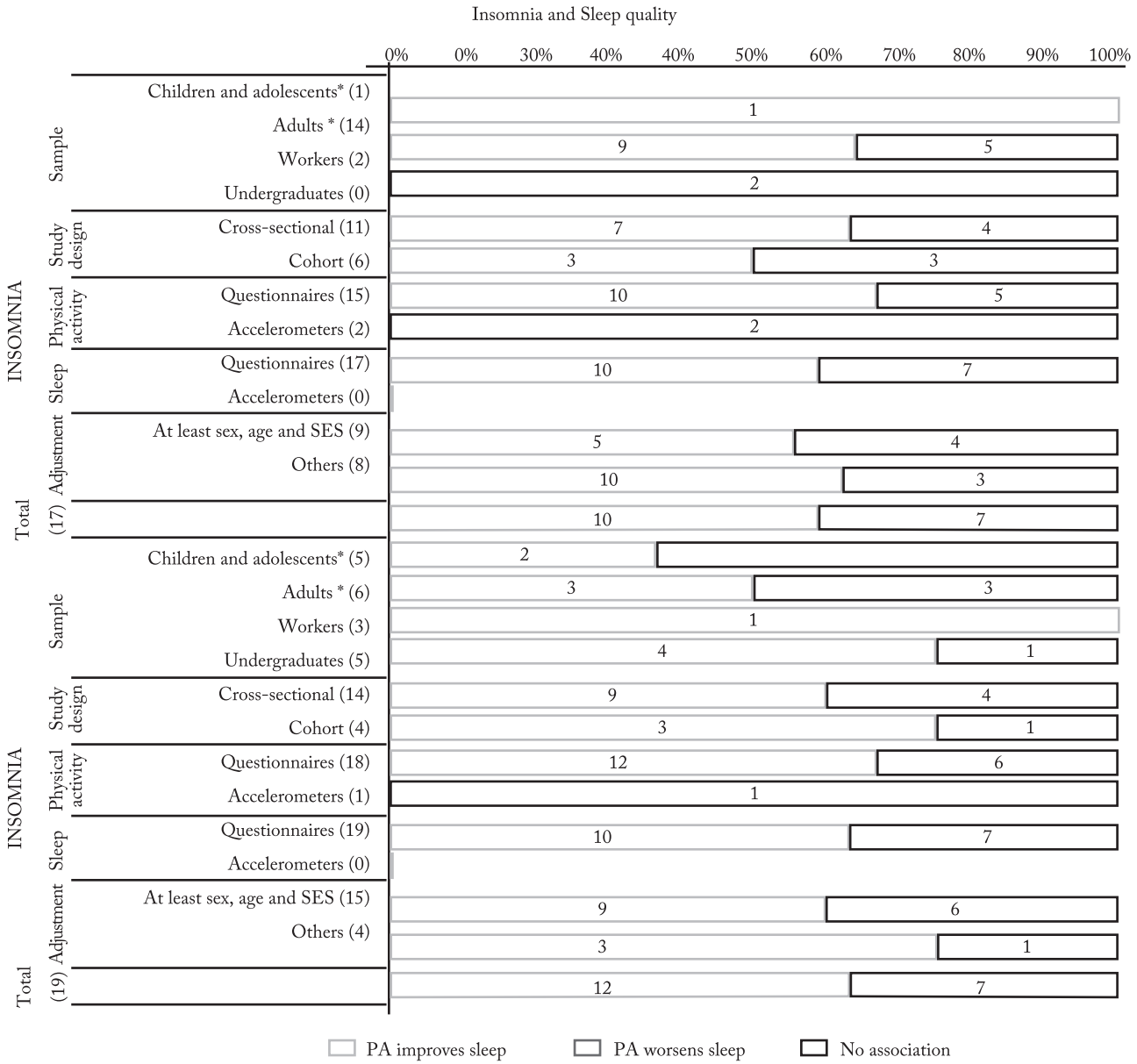

Figure 4 – Effects of physical activity on insomnia and sleep quality according to study characteristics.
*Population-based samples

studies and representative samples of workers and undergraduate students. In general, results are inconsistent for short and continuous sleep duration but for long sleep, insomnia and sleep quality, physical activity results seem to play an import role for improvements on these outcomes. The most studies were cross-sectional, were performed in high-income countries, and showed a large variability of instruments for sleep and physical activity.

A review published in 2017 showed that physical activity had an important influence on sleep but some methodological aspects of this review should be highlighted[74]. The main differences between the cited review and the present study were the types of study designs included, population, key-words and the search period. Regarding data bases, it is not clear which were used in Dolezal et. al.[74] review. Authors have not clarified quality aspects of studies such as method used to measure sleep and physical activity/exercise and adjustment[74]. The present study had no limit on publication years and included only studies with representative samples of general populations, workers, and undergraduates. The other review included any kind of samples, and studies without comparison groups. Furthermore, the previously published systematic review included only papers published from 2013 to 2016. In this period, our review

detected 23 studies, but only one study was included in both reviews[32]. This may lead to important differences in the inclusion criteria for the studies in each case.

The variety of instruments for physical activity measurement in the selected studies must be highlighted, ranging from lists of activities and accelerometers to questions about meeting the guidelines on exercise frequency during the week. More complete information about physical activity including domain, frequency, intensity, and duration could be important for a better understanding of the relationship. The comparison between studies was difficult due not only to the used instrument, but also to the operational definition of physical activity. Furthermore, separating the effects of physical activity and exercise on sleep was difficult due to the lack of information in the questionnaires/ questions to conclude if exposure was physical activity or exercise. The low accuracy or poor information in questionnaires of physical activity may lead to important bias in results and these measurement errors may reduce the magnitude of the tested association. In addition, the understanding of questionnaires is dependent on other individual and environmental characteristics as socioeconomic status, age and seasonal variation[75]. Studies with poor adjustment or with questionnaires developed to other population than the one studied may contribute to biased findings.

Regarding physical activity intensity, few studies could verify the association of sleep with light, moderate and vigorous physical activity separately. Buman et al.[31] found positive effects of all intensities combined on different sleep outcomes[31]. Tsunoda et al.[64] found that light and moderate physical activity decreased, respectively, 14% and 19% the risk for short sleep duration, while no effect was identified for moderate physical activity[64]. Energy expenditure of different intensities and how this is captured by physical activity instruments may explain the observed differences[15]. This fact reinforces the need of more studies on this topic.

The dose response relationship is difficult to be assessed in this review as most studies did not provide enough information for such evaluation. Some evidence was available in three studies. Inoue et al.[30] found an odds ratio of 0.75 to difficulty of initiating sleep with physical activity performed 1 to 2 days in a week compared to none[30]. The odds ratio for 3-4 days was 0.98 and for 5-7 days was 0.66[30]. In the same direction, Morgan et al.[23] in a cohort comprised by elderly individuals, showed that the magnitude of association was almost the same in individuals in medium and low categories of physical activity; they presented an odds of insomnia almost three times higher compared to those in higher category of physical activity[23]. On the other hand, Liu et al.[22] in a study with adolescents using physical activity frequency (none/ 1-2 times per week/ 3 or more times per week) found an odds ratio 2.7 higher to insomnia in individuals performing 1-2 days of physical activity comparing to three or more times per week. The odds ratio to individuals with no activity days was 3.3[22]. This evidence is not consistent; thus, more studies exploring dose-response relationships between physical activity and sleep outcomes are needed.

In terms of sleep assessment, the most common outcome was sleep duration evaluated in 28 studies but with different approaches. Also, in general these studies did not used complex questionnaires but calculated sleep duration from simple questions about sleep onset and sleep end. The recommended sleep duration in adults is seven hours per day[14] without a maximum limit, although some studies had showed that long sleep may increase risk to mortality and cognitive impairment[76-78]. The sleep duration approach (continuous, adequate, short or long) and its cut off point varied greatly across the studies. Questionnaires to measure insomnia, in general included three questions: difficulty to sleep, difficulty to maintain sleep and too early wake up. These questions were followed by additional questions in some studies. Other structured questionnaires with high reliability were used such as Athens Insomnia Scale (Cronbach's alpha of 0.90)[79], Jenkins Sleep Questionnaire[80] and Insomnia Severity Index (Cronbach's alpha of 0.90)[81]. Studies assessing sleep quality mostly used Pittsburgh Sleep Quality, which presents sensitivity of 89.6% and specificity of 86.5%[82].

Literature shows short- and long- effects of exercise on sleep outcomes[16,17]. Authors discuss that lower levels of physical activity may result in sleep architecture changes as there is an increase in duration and a decrease in latency[16,17]. Acute effects of physical activity on sleep are more related to thermoregulation, energy conservation, increases in growth hormone levels, and decreases in cortisol levels[15,16]. On the other hand, regular exercise can potentialize physical activity's effects on sleep outcomes[17] by increase physical fitness, improve body composition and circadian rhythm regulation, factors which are positively associated with healthy sleep patterns[16].

Acute effect is very difficult to measure. Cross-sec-

tional studies cannot capture the essence of short-term effect of physical activity only with questionnaires. This is partly due to all questionnaires are related to habitual physical activity or physical activity in last week, a proxy of regular physical activity. Acute physical activity can only be assessed more easily by accelerometer with analyses of a 24 hours period, despite of challenges related to logistics and resources limitations in use of accelerometers. Recently, some recent studies started to analyse the time spent in different activities over a day[83] and in the future, studies with large representative samples and considering effect of daily activities performed over sleep at the subsequent night will contribute to a better understanding of the acute effect of physical activity.

Studies evaluating short sleep, in general, did not find any association and those which found an association, were in the direction of reducing proportion of short sleep. However, most studies with long sleep duration found associations showing decreased risk of this outcome. This suggests that, in a given point in sleep duration, the effect of physical activity changes the direction and thus may reduce both short and long sleep. Results of studies evaluating continuous duration were divergent, possibly by the lack of a central reference category (e.g. 7-8 hours). Still, it is possible that physical activity plays a role only in individuals with many hours of sleep. If physical activity has a mechanism of tissue restoration, as previously studies highlight[15,16], it is possible that active individuals do not need a long sleep period to restoration in comparison with inactive individuals.

It is important to highlight that although the role of physical activity in sleep duration is not so clear, results about sleep quality and insomnia seem to be more consistent. In general, physical activity seems to improve sleep quality and reduce the risk of insomnia, independently of the study design (longitudinal or cross-sectional). A more restorative sleep by thermoregulation, tissue restoration or physical fitness improved by physical activity[15,16] may lead to better sleep but not necessarily longer or shorter sleep. A new approach in sleep studies encompassing more sleep health aspects than just duration is necessary. Buysse et al.[84] commented that sleep health has different dimensions associated to different variables[84]. Thus, it is possible that physical activity has a more important association with sleep quality and disorders as insomnia than architecture data, as sleep duration.

Some reports about quality of studies included should be highlight. Although the majority of studies reported data for response rates, in many cases this rate did not reach 60% of the original sample[8,25,34,58,59,64,66,67]. Moreover, about 20% of studies did not report rates regarding the original sample of study (sometimes only the analytic sample regarding the collected data)[13,24,31-33,39,41,44,52,56,60,61,68]. In these cases, the possibility of bias is unclear. Furthermore, some specific studies had sampling processes which were likely influenced by sample bias. For example, Ekstead et al.[61] used data from a population that was previously selected for a school intervention[61]. Although the authors comment that the intervention had no effect on the proposed association, as a school-based survey it seems inadequate, since this design did not require the representativeness of a given population[61]. Two studies[31,45] used sampling processes based on Internet and/or telephone surveys; this can be an important limitation, since not all populations have access to such services. It is probable that individuals who take part in these studies had higher educational levels, socioeconomic status, and access to health services than the general population. Better living conditions are also associated with higher levels of physical activity and lower sleep disorders, but it is probable that these conditions affect the frequency of exposure and outcome but not the association between them.

Regarding the adjustment for possible confounding, most of studies adjusted or stratified for sex and age, but adjustment for socioeconomic or educational status was less frequent. Although the pattern of association comparing studies adjusted to sex, age and socioeconomic status and other studies did not change drastically, these socioeconomic characteristics are important confounding variables for this association. Several authors found that poor individuals or those with lower education had more sleep problems[7,8,10,13,27,37]. Literature has also showed that more disadvantaged groups are more physically inactive[85,86]. Therefore, the results of studies that did not consider socioeconomic or educational status should be carefully observed, mainly in low-income countries where socioeconomic inequalities in health are more pronounced. Few studies present cohort designs and adequate adjusted analyses but, in general, these works showed that the association between physical activity and sleep persist even after the adjustment for possible confounders. Moreover, it should be noted that in this review, cohort studies did not find negative effects of physical activity on all evaluated sleep outcomes.

This review has some limitations such as heteroge-

neity of data for physical activity which did not allow us to draw more specific conclusions about the magnitude of the effect studied, intensity of physical activity and dose-response relationship. Furthermore, bidirectionality in this theme is relevant. However, this issue is scarce in the literature, due to difficulties in data acquisition, especially. In other hand, this study summarizes results about association of physical activity on sleep in many ages and contexts and identifies the remaining gaps to be addressed in future research on this topic.

In the future, it is relevant to reinforce some topics that should be included in the research agenda: (a) utilisation of comparable instruments for sleep outcomes that do not limit the evaluation to sleep duration only; (b) utilization of clear and comparable operational definitions of physical activity measuring frequency, intensity, and duration; (c) attention to important adjusted variables; and (d) more longitudinal studies with representative samples of low- and lower-middle-income countries are necessary.

Physical activity seems to be positively associated with lower long sleep, and negatively associated with insomnia and poor sleep quality. The results for short and continuous sleep duration are not consistent. The studies included in this review used heterogeneous measures to evaluate both exposures and outcomes and standardization of instruments is needed to obtain combined effect measures.

Conflict of interest

The authors declare no conflict of interest.

Authors'contribution

Wendt A and Flores TR, participate of study conception. Wendt A, Flores TR and Wehrmeister FC, participated in search, data selection and extraction. Wendt A, Flores TR, Wehrmeister FC and Silva ICM, wrote and participate in critical review. All authors approved final version of paper.

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Supplementary Table – Detailed information of selected studies (n = 57).

Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
Morgan & Clarke[23] Longitudinal	Elderly (65+ years) N in follow-up = 690 England	Questionnaire: "Do you ever have problems sleeping?" If participant answer "often" or "all the time", it was considerate insomnia. The authors calculated the insomnia incidence.	Questionnaire: Habitual PA: indoor, outdoor, social and practical activities. The questionnaire was analyzed with a pca (only the first component was used). Score continuous of a pca analyze (divided in PA high, intermediate, low). The low category was the reference.	Comparing to high PA, individuals in intermediate PA category, presented odds 2.89 higher to insomnia (CI95%: 1.91-3.62). Individuals in low PA category presented odds 2.94 higher for insomnia comparing to high PA (CI 95%: 2.14-3.64).
Sherrill et al.[24] Cross-sectional	Adults (40+ years) N = 722 USA	Questionnaire: "Have you ever been troubled by any of the following problems: a. trouble falling asleep b. trouble staying asleep c. not enough sleep d. waking up too early and not being able to get back to sleep" If participant answer yes at least one of 4 questions was considered insomnia.	Questionnaire: a. "How many city blocks or equivalent do you regularly walk each day? What is your pace of walking?" b. "Are you participating in any exercise program specifically designed to improve your physical health?" c. "On a usual weekday/weekend day, how much time do you spend doing vigorous activity (sports, jogging, sustained swimming, brisk walking, or bicycling)?". The answers generated the follow variables: a. Walk >6 blocks per day at a casual pace or at a brisk pace; b. Participate in exercise program c. Regular activity at least once a week d. Vigorous activity (> 1h/day) in weekdays and weekends.	Walk >6 blocks per day at average pace decreased the odds of insomnia in 0.67 times (CI 95%: 0.46-0.97). Only for men, walk >6 blocks per day at a brisk pace, decrease the odds of insomnia in 0.50 times (CI 95%: 0.27-0.93). Participating in exercise program decreased the odds of insomnia in 0.52 times (CI 95%: 0.30-0.92). Regular activity at least once a week decreased the odds of insomnia in 0.71 times (CI 95%: 0.50-0.99). Only for women, vigorous activity in weekends and participate in exercise program (interaction) increased the odds of insomnia in 2.16 times (1.02-4.58).
Ito et al.[25] Cross-sectional	Adults (65+ years) N = 518 Japan	Questionnaire: a. "How many hours do you sleep at night on average?" b. "How long does it take from going to bed to falling asleep? (answer:<10 min,10–30 min, 30–60 min, or >60 min)" c. "How many times do you usually wake up at night? (answer: never, once, twice, or three times or more)" d. "How do you feel when you wake up in the morning? (answer: good or bad)" Insomnia was evaluated checking the follow aspects: a. difficulty in falling asleep (difference between bedtime and time of falling asleep exceeded 30 min) b. Frequent awakening at night (more than twice) c. feeling not rested in the morning (answer "bad" to this question).	Questionnaire: no information. The variable generated was "PA more than once a week".	No association to any variable related to insomnia.

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Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
Kim et al.[46] Cross-sectional	Adults (20+ years) N = 3,030 Japan	Questionnaire: a. "Do you have difficulty falling asleep at night?" b. "Do you wake up during the night after you have gone to sleep?" c. "Do you wake up too early in the morning and have difficulty getting back to sleep?" The difficulty initiating sleep, difficulty in maintaining sleep and wake up too early were evaluated as different components of insomnia. The outcome insomnia (positive answer to any question) also was evaluated.	Questionnaire: no information. The generated variable was "habitual exercise".	No association with difficulty initiating sleep and wake up to early. No habitual exercise increased the odds of maintaining sleep in 1.3 times (CI 95%: 1.0-1.7) (p < 0.05). No habitual exercise increased the odds of insomnia in 1.3 times (CI 95%: 1.0-1.6) (p < 0.05).
Liu et al.[22] Cross-sectional	Adolescents (12 to 18 years) N = 1,365 China	Questionnaire: a. "How many hours do you sleep at night?" b. "Do you have difficulty getting to sleep at night? (never/sometimes/often)" c. "Do you awaken during the night and have trouble getting back to sleep? (never/sometimes/often)" d. "Do you awaken too early in the morning and have trouble getting back to sleep? (never/sometimes/often)". If participant answer "often" at least one of these: difficulty initiating sleep, difficulty in maintaining sleep or wake up too early, was considerate insomnia.	Questionnaire: no information. The generated variable was exercise frequency with categories "no physical exercise", "physical exercise 1/2 times per week" and "physical exercise 3 times per week or more". The reference category was 3+ times per week.	Compared to individuals that did exercise 3 or more times in a week, individuals performing 1-2 times per week presented odds 2.7 times higher to insomnia (CI 95%: 1.23-5.89). Individuals who didn't exercise, presented odds 3.29 times higher to insomnia (CI 95%: 1.98-5.46).
Ban & Lee[68] Cross-sectional	Undergraduate students (17 to 41 years). N = 1,414 Korea	Questionnaire: "On the average, how much sleep do you get each night?" Sleep duration was evaluated continuous.	Questionnaire: no information. The generated variable was exercise frequency with categories "never or rarely", "irregularly", "regularly".	No association.
Janson et al.[26] Cross-sectional	Adults (30-69 years) N = 2,668 Sweden	Questionnaire: Questions about difficulty falling asleep and maintaining sleep. Options of answer: 1 (none) to 5 (very severe). If participant answer "severe" or "very severe" was considerate insomnia.	Questionnaire: Validated instrument with questions about leisure activities (with different intensities) Physical inactivity was defined as category 1 (i.e., spending most time in front of the television, reading and other sedentary activities).	Physical inactivity increased the odds of insomnia in 1.43 times (CI 95%: 1.03-1.97).

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Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
Kronholm et al.[27] Cross-sectional	Adults (18+ years) N = 7,551 Finland	Questionnaire: a. Duration: "How many hours do you sleep in 24 hours?" b. Insomnia: "Have you had some of the following usual symptoms and troubles within the last month (30 days) sleeping disorders or insomnia?" Short sleepers: ≤6 hours Mid-range sleepers: 7-8hours Long sleepers: 9+hours Sleep duration continuous also was used (to dose-response). Insomnia: yes/no.	Questionnaire: PA in leisure-time. The variable generate result in follow categories: "not much", ">4 h/week", "exercise >3h/week" and "competition sports".	No association in the best adjusted model.
Nixon et al.[47] Cross-sectional	Children (7 years) N = 519 New Zeeland	Accelerometry: MTI accelerometer based on sleep log. Continuous variables: Sleep onset time was defined as the first 3 consecutive minutes of sleep in the scoring interval after the reported bedtime. Sleep end time was defined as the time of the last 5 consecutive minutes of sleep prior to the reported rise time. Sleep period time (sleep duration) was the time from sleep onset to sleep end time. Short sleep: <9h.	Questionnaire: a. "Compared with other children, does your child run around outside?" Possible responses were "A lot," "the same," or "less." b. How many times a week does your child engage in vigorous physical activity long enough to make him/her breathe hard?" Possible responses were "Never" or "occasionally," "once or twice a week," "three or more times a week." c. "During a normal week, how many hours a day (24 hours) does your child watch television?" Possible responses were "<1," "1-3," or ">3 hours." Accelerometry: MTI accelerometer The generate variables were: a. Runs around a lot outside (parent report) b. Vigorous activity at least once a week (parent report) c. Total daytime movement counts (change in sleep duration per 105 counts) d. Mean daytime movement counts/min (change in sleep duration per 10^2 counts/min e. sedentary (min) f. moderate (min) g. vigorous (min).	No association.
Saeki et al.[62] Longitudinal	Workers (age average: 45.8 (8.1)) N = 827 Japan	Sleep quality: PSQI Poor sleep quality ≥6 points.	Questionnaire: exercise frequency. Weekly frequency was classified as "regular exercise" and monthly frequency or less as "not practicing".	Regular exercise increases the odds of good sleep quality 3 years after in 1.88 times (CI 95%: 1.29-2.75).

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Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
Stranges et al.[7] Cross-sectional	Workers (45 to 69 years) Adults (35 to 79 years) N workers = 6,472 N adults = 3,027 United Kingdom (workers) and USA (adults)	Questionnaire: United Kingdom: "How many hours of sleep do you have on an average weeknight?" Response categories were 5 hours or less, 6 hours, 7 hours, 8 hours, and 9 hours or more. USA: "On the average, how many hours did you sleep each night during the last 5 weekday nights (Sunday–Thursday)?" All data were categorized into: Short sleep: <6h Normal sleep: 6-8h Long sleep: >8h.	Questionnaire: United Kingdom: Number of occasions and hours they had spent engaging in a series of specific activities over the past 4 weeks. Activities classified in different intensities according to metabolic equivalent. High PA: subjects who reported at least 1.5 hours of vigorous activity per week Low PA: subjects who reported no vigorous activity or less than 1.5 hours of vigorous activity per week. USA: Seven-Day Physical Activity Recall questionnaire used in the Stan ford Five-City Project. Classification according to equivalent metabolic PA was divided n high and low by median according to equivalent metabolic.	United Kingdom: No association. USA: Low PA was associated to odds of 0.60 lower to short sleep (CI 95%: 0.46-0.78) and to odds of 1.60 higher to long sleep (1.09-2.34).
Krueger & Friedman[10] Cross-sectional	Adults (18+ years) N = 110,441 USA	Questionnaire: "On average, how many hours of sleep do you get in a 24-hour period?" The item ranged from 0 to 23. Sleep duration was categorized in <5hours, 6hours, 7 hours, 8 hours and 9 or more hours. Reference category: 7 hours.	Questionnaire: Sum of weekly frequency of 3 items: a. leisure-time activity that caused heavy sweating or large increases in breathing or heart rate b. leisure-time that caused light sweating or slight-to-moderate increases in breathing or heart rate c. leisure-time to improve strength. PA index was standardized and results interpreted at standard deviation (sd) level.	The increase of 1 sd in PA index, increased the odds of sleep <5hour in 1.05 times compared to 7 hours (CI 95%: 1.02-1.09). No association to 6 hours. The increase of 1 sd in PA index, reduced the odds of sleep 8h in 0.96 times compared to 7 hours (CI 95%: 094-0.98). The increase of 1 sd in PA index reduced the odds of sleep 9 or more hours in 0.90 compared to 7 hours (CI 95%: 0.87-0.93).
LeBlanc et al.[45] Longitudinal	Adults (18+ years) N = 464 Canada	Questionnaires: Sleep quality: PSQI Poor sleep quality: ≥6 points Insomnia: ISI (Insomnia Severity Index) Absence of insomnia (0–7) Subthreshold insomnia (8–14) Moderate insomnia (15–21) Severe insomnia (22–28) Also, the answers in two questionnaires (ISI and PSQI) and question about medication use to asleep were combined to create 3 groups: Insomnia syndrome, Insomnia symptoms and Good sleepers.	Questionnaire: "How many times per week do you spend more than 20 minutes exercising in your free time?".	No association.
Li et al.[48] Cross-sectional	Children (5 to 12 years) N = 20,778 China	Questionnaire: Children's Sleep Habits Questionnaire. Bed time and wake time informed by parents Short sleep: <9h.	Questionnaire: no information. The generate variable was PA frequency with follow categories: "usually/often" and "occasional/no".	No association.

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Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
Paparrigopoulos et al.[8] Cross- sectional	Adults (18+ years) N = 1,005 Greece	Questionnaire: Athens Insomnia Scale (AIS), which is an 8-item standardized self-assessment psychometric instrument designed for quantifying sleep difficulty based on the ICD-10 criteria.	Questionnaire: IPAQ. Subjects with score on IPAQ less than 30 were characterized as physically inactive.	Inactive individuals presented odds 1.42 times higher to insomnia (CI 95%: 1.01-2.03).
Park et al.[28] Cross-sectional	Adults (18 to 64 years) N = 6,510 Korea	Questionnaire: a. "On average, how many hours do you sleep each night on weekdays?" b. "During the past month, how often have you had trouble sleeping due to difficulty falling asleep?" c. "During the past month, how often have you had trouble sleeping because you often woke up after falling asleep?" d. "During the past month, how often have you had trouble sleeping because you woke up too early and could not go back to sleep?" e. "During the past month, have you ever woken up feeling tired and not refreshed?" Sleep duration was categorized in <5hours, 6hours, 7 hours, 8 hours and 9 or more hours. Reference: 7 hours The presence of difficulty initiating sleep, difficulty maintaining sleep, early morning awaking and non-restorative sleep were defined by three or more sleep-related difficulties per week.	Questionnaire: IPAQ-short. The PA was classified as follow: "inactive", "minimally active" and "health-enhancing".	Individuals in health-enhancing category presented odds 1.44 times higher to sleep 5 hours compared to 7h sleepers (CI 95%: 1.14-1.81). No association to long sleep.
Hense et al.[49] Cross-sectional	Children (2 to 7 years) N = 16,223 Italy, Estonia, Cyprus, Belgium, Sweden, Hungary, Germany and Spain	24-h recall (SACINA): information of parents/guardian. Sleep duration was used in continuous way.	Accelerometry: Actigraph GT1M and ActiTrainer with cut-offs for moderate to vigorous activity according to Sirard et al. Wore in waist for 3 days. The variable generated was minutes of MVPA.	No association.
Pesonen et al.[50] Cross-sectional	Children (8 years) N = 297 Finland	Accelerometer: Actiwatch AW4, in non-dominant wrist for 7 days (with event maker). The generate variable was standardized sleep duration.	Accelerometer: Actiwatch AW4, in non-dominant wrist for 7 days (prediction equation proposed by Heil et al) The generated variables were: Mean of counts in entire day (standardized); MVPA 9a.m. to 6p.m. (1hours vs less); MVPA 6.01p.m. to 9p.m. (1 hour vs. less).	Increase of 1 sd in mean of counts per day, decreased 0.30 sd in sleep duration (CI 95%: -0.36; -0.25). Do at least 1 hour of MVPA from 9a.m. to 6p.m. decreased 0.21 sd in sleep duration (CI 95%: -0.31; -0.12). Do at least 1 hour of MVPA from 6.01p.m. to 9p.m. decreased 0.16 sd in sleep duration (CI 95%: -0.27; -0.05).

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Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
Hoefelmann et al.[63] Cross-sectional	Workers N = 52,774 Brazil	Questionnaire: "How often do you think that you sleep well?" Answers sometimes, never and rarely were classified as poor sleep quality. Answers always and almost always were classified as good sleep quality.	Questionnaire: no information (leisure-time only). The generated variable was categorized in "active" and "inactive".	Inactive men presented odds to poor sleep quality 1.18 times higher than actives (CI 95%: 1.11-1.26). Women showed similar pattern with odds of 1.18 too (CI 95%: 1.07-1.31).
Narang et al.[51] Cross-sectional	Children and adolescents (age average = 14.2 years) N = 3,372 Canada	Questionnaire: PSQI.	Questionnaire: no information. The generated variable was categorized into: "0-2 days/week", "3-4 days/week", "5.7 days/week".	The means of PSQI scores decreased according to increase in frequency of PA indicating a better sleep quality (p < 0.001) Mean of PSQI score in 0--.2 days of PA: 7.4 (5.9); Mean of PSQI score in 3-4 days of PA: 7.2 (5.6); Mean of PSQI score in 5-7days of PA: 6.3 (5.6).
Tu et al.[29] Cross-sectional	Adults (40 to 70 years) N = 68,832 China	Questionnaire: "In the past two years, how many hours did you sleep each day (including sleeping during the day and night, but not including time if you woke up between two periods of sleep)?" The answers were categorized into: 4 hours; 5 hours; 6 hours; 7 hours (reference); 8 hours; 9 hours and 10 hours.	Questionnaire (no information). The generated variable was "exercise participation".	Participation in exercise decreased the odds of sleep at least 4 hours in 0.84 times (CI 95%: 0.76-0.92) and sleep 10 hours or more in 0.75 times (CI 95%: 0.68; 0.82) compared to 7 hours.
Ekstedt et al.[61] Cross-sectional	Children (6 to 10 years) N = 1,231 Sweden	Accelerometer: Actiwatch® [AW], model 4, in wrist. The final variable was standardized Total sleep time.	Accelerometer: Actiwatch® [AW], model 4, in wrist. The generated variables were: Total counts per minute and MVPA (minutes).	No association.
Haario et al.[20] Longitudinal	Workers (40 to 60 years) N = 6,458 Finland	Questionnaire: Jenkins Sleep Questionnaire evaluating trouble falling asleep, waking up several times per night and trouble staying a sleep.	Questionnaire: The respondents were asked about their average weekly hours of physical activity during leisure time or commuting within the previous 12 months in four grades of intensity: walking, brisk walking, jogging and running or equivalent activities. Each intensity grade had five response alternatives: no activity, 0–½ h per week, ½–1 h per week,2–3 h per week and 4 h or more per week. Total physical activity was measured by approximate metabolic equivalent. Physical activity was dichotomized into physical inactivity (fewer than 14 MET-hours per week) or physical activity (14or more MET-hours per week).	No association.

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Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
Inoue et al.[30] Longitudinal	Elderly (65+ years) N = 14,001 Japan	Questionnaire: Difficulty falling asleep lasting for 30 minutes or longer; Waking up frequently during the night; Waking up too early in the morning and being unable to go back to sleep requiring the use of hypnotics to fall asleep. At least one symptom was considerate insomnia.	Questionnaire: "How many days a week the subjects spent 30 min or more walking (hereafter referred to as Walk), performing light work (Work; e.g., office or home-based light work, housework), and exercising (Exercise; e.g., recreational/sporting activities)." Walk, and exercise were classified into: none, 1–2 days/week, 3–4 days/week, and 5 or more days/week.	Exercise 5-7d/week decreased the odds of difficulty maintaining sleep in 0.66 times (CI 95%: 0.51-0.85).
Yu et al.[69] Cross-sectional	Undergraduate students (age average = 19.2 (1.1) N = 5,806 China	Questionnaire: PSQI Poor sleep quality: >7 points.	Questionnaire: at least one day or night of exercise (Physical activity rating scale - 3/PARS-3). The generate variable was categorized into: only day exercise; only night exercise; day and night exercise.	Day exercise reduced the odds of poor sleep quality in 0.79 times (CI 95%: 0.65-0.96) compared to not exercise group. Similar result to exercise day or night with odds of 0.74 (CI 95%: 0.61-0.89). No association to night exercise isolated.
Al-Hazzaa et al.[52] Cross-sectional	Children and adolescents (age average = 16.6 (1.1)). N = 2,868 Saudi Arabia	Questionnaire: number of typical sleeping hours per day (night and day). Sleep duration was categorized into <8h and 8+ hours.	Questionnaire: The questionnaire collects information on frequency, duration and intensity of a variety of light, moderate and vigorous-intensity PA during a typical week. The questions covered transport, household, fitness and sports activities domains. PA were assigned metabolic equivalent (MET) values based on the compendium of PA. Participants were classified into three groups (low active, medium active and high active) based on tertile of total METs-min per week.	Individuals in low PA category presented odds 1.33 higher to adequate sleep (8+h) compared to high PA (CI 95%: 1.08-1.61).
Buman et al.[31] Cross-sectional	Adults (23-60 years) N = 1,000 USA	Questionnaire: Overall sleep quality was measured with one 4-item Likert-type question with 'very good,' 'fairly good,' 'fairly bad,' and 'very bad' response options. Answers fairly good/very good were considerate good sleep. Total sleep time (TST) was assessed in hours and minutes "on average worknights or weeknights not including naps. Adequate duration: 7-8.5hours.	Questionnaire: IPAQ_+ typical time day. The generated variables were: vigorous, moderate and light exercise in morning, afternoon, evening or none.	Vigorous exercise in the morning increased the odds of good sleep quality in 1.88 times ($p < 0.001$) but was not associated to sleep duration. Moderate exercise in the morning increased the odds of good sleep quality in 1.53 times ($p < 0.05$) but was not associated to sleep duration. Light exercise in the evening increased the odds of adequate sleep duration in 1.77 times ($p < 0.05$).
Chen et al.[53] Cross-sectional	Children and adolescents (age average = 15.6 (2.1)) N = 4,801 China	Questionnaire: Adolescent Sleep Wake Scale. Sleep habit information included bedtime, wake-up time, and sleep duration on weekdays (from Monday to Friday) and on weekends (Saturday and Sunday). For the statistical analysis, the number of minutes was divided by 60, multiplied by 100, and added to the number of hours to obtain a metric variable. Short sleep was defined as <8 hours.	Questionnaire: no information. The generated variable was categorized into: <1 and ≥1 h/day in weekdays and weekends.	Less than 1h of PA per day on weekends increased the odds of short sleep in 1.49 times compared to 1h or more (CI 95%: 1.11-1.99) PA on weekdays not was associated.

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Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
Chen et al.[32] Longitudinal	Elderly (65+ years) N = 1,128 China	Questionnaire: PSQI Poor sleep quality: ≥6 points.	Questionnaire: Physical Activity Scale for Elderly. Totals for each category of activity were divided by the mean into low (Lo) and high (Hi) groups. Then, four groups were created (Lo-Lo, Lo-Hi, Hi-Lo, Hi-Hi(reference)) according to mean splits for each activity in baseline and follow-up.	Lo-Lo group of leisure-time PA present odds 9.9 times higher to incidence of poor sleep quality (CI 95%: 2.25-44.1) compared to Hi-Hi group. Similar results to Hi-Lo group with odds of 8.73 (CI 95%: 1.90-40.2) and Lo-Hi group with odds of 5.6 (CI 95%: 1.1-27.7).
Feng et al.[70] Cross-sectional	Undergraduate students (age average = 19.0 (0.9)) N = 1,106 China	Questionnaire: PSQI Poor sleep quality: >5points.	Questionnaire: The frequency of PA (How often do you sport and/or vigorous free play each week with 30 minutes at least per day?) was assessed by using the following options: daily, 5–6 days/week, 3–4 days/week, 1–2 days/week, and less than once per week.	PA presented interaction with screen time. Adolescents with high PA and screen time ≤2hours presented odds of poor sleep quality 0.51 time lower compared to group low PA and >2h screen time (CI 95%: 0.27-0.91).
Monteiro et al.[33] Cross-sectional	Elderly (65+ years) N = 689 Brazil	Questionnaire: Nottingham Health Profile. Symptoms of insomnia: Difficulty initiating sleep difficulty maintaining sleep early awakening non-restorative sleep.	Questionnaire: Minnesota Leisure Activity Questionnaire. At least one of following activities: walking, gymnastics at home, gym, ballroom dance.	No association.
Stea et al.[54] Cross-sectional	Adolescents (15 to 17 years) N = 2,432 Norway	Questionnaire: "When do you usually get out of bed on a school day? and When do you usually go to bed on a school night? on a typical weekday." Short sleep was defined as <8 hours.	Questionnaire: "How many hours per week do you spend on doing sports/physical activity in a way that makes you breathless or sweat?' Response alternatives were: '0 h, 1–2 h, 3–4 h, 5–7 h, 8–10 h and 11 h or more. For the statistical analysis, not participating in 60 min of physical activity every day was characterized as health-risk behaviour.	Did not participate in 60 min of physical activity every day increased the odds of short sleep in 1.33 times (CI 95%: 1.05-1.68).
Tsunoda et al.[64] Longitudinal	Workers (age mean = 48.9 (11.4)). N = 6,185 Japan	Questionnaire: Question about sleep duration. Short sleep was defined as <6 hours.	Questionnaire: Frequency, duration and intensity of activities. The final variables were: light, moderate and vigorous PA at least once a week.	Light PA decreased the odds of short sleep in 0.86 times (CI 95%: 0.75-0.97) Vigorous PA decreased the odds of short sleep in 0.81 times (CI 95%: 0.67-0.97).
Uhlig et al.[34] Cross-sectional	Adults (20+ years) N = 40,535 Norway	Questionnaire: "How often during the last 3 months has it occurred that you: a. Had difficulties falling asleep at night? b. Woke up repeatedly during the night? c. Woke up too early and couldn't get back to sleep? d. Felt sleepy during the day?" For all the four questions there were three response options: 'Seldom or never', 'Sometimes', and 'Several times a week. Subjects were diagnosed with insomnia if answering 'several times a week' on at least one of the aspects.	Questionnaire: no information. The generated variable was categorized into: never or less than once a week (physically inactive), once a week, two or three times per week, or daily or nearly daily.	Inactive individuals presented odds of insomnia 2 times higher than actives (CI 95%: 1.7-2.4).

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Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
Jiang et al.[55] Cross-sectional	Children and adolescents (age average = 11.5) N = 6,247 China	Questionnaire: Sleep duration was calculated as the time lapse between bedtime and wake up time. Sleep quality was assessed using the Multidimensional Sub-health Questionnaire of Adolescents	Questionnaire: After-school leisure-time physical activity (LPA) was measured by asking students how long they spent in light (e.g. walking), moderate (e.g. jogging, badminton) and vigorous (e.g. tennis, swimming) physical activity and summed to determine total LPA.	Girls in secondary school presented a positive association of LPA and sleep duration (B = 0.059; p = 0.030). No association to sleep quality and boys.
Tsunoda et al.[65] Longitudinal	Workers (age average in adults: 45.7 (8.8); age average in elderly = 65.6 (4.7)). N = 7,061 Japan	Questionnaire: Question about sleep duration. Short sleep was defined as <6 hours.	Questionnaire: Frequency, duration and intensity of activities. Moderate Low PA corresponds to approximately 3–5 METs, Moderate High PA corresponds to 5–7 METs, and Vigorous PA corresponds to ≥7 METs. Moderate Low PA, Moderate High PA, and Vigorous PA were, respectively, categorized into dichotomous variables of "less than once a week" and "once a week or more.	No association.
Wu et al.[71] Cross-sectional	Undergraduate students (age average = 19.2). N = 4,747 China	Questionnaire: PSQI Poor sleep quality: >7 points.	Questionnaire: "On how many of the past 7 days did you do exercises to strengthen or tone your muscles, such as push-ups, sit-ups, or weight lifting?' The responses range from0 to 7 days. High PA was defined as at least three days per week of exercise. The Physical Activity Rank Scale-3 (PARS-3) was used to assess the PA rank of the college students. The PARS-3 is a self-rated questionnaire that assesses PA rank over a 1-month time period. PA rank was measured according to the intensity, time and frequency of exercise, respectively, with the following equation: PA rank = intensity × time × frequency. By PARS-3, The resulting score (≤19, 20–42 and ≥43) was used to determine a low, medium or high PA rank, respectively.	Individuals in high rank of PA presented odds 0.69 lower to poor sleep quality compared to low rank (CI 95%: 0.49-0.99). Individuals in high PA and <2h screen time (interaction) presented odds 0.48 lower to poor sleep quality (CI 95%: 0.29-0.81).
Yoon et al.[13] Cross-sectional	Adults (40 to 69 years) N = 84,094 Korea	Questionnaire: "On average, how many hours of sleep did you get per day during the past year (including nap times)?" Four response categories were given:<6 hours, 6–7 hours (reference), 8–9 hours, and ≥10 hours.	Questionnaire: "Do you do any sports regularly until you sweat?"	For men, non-exercise group presented odds 1.48 times higher to long sleep (≥10h) compared to exercise group (CI 95%: 1.23-1.78). For women, non-exercise group present odds 1.07 times higher to moderately long sleep (8-9h) compared to exercise group (CI 95%: 1.03-1.12). Similar results to long sleep (≥10 h) with odds 1.26 (CI 95%: 1.11-1.42). No association to short sleep for both sexes.

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Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
Chang et al.[72] Cross-sectional	Undergraduate students (18 to 25 years). N = 1,230 (Taiwan) China	Questionnaire: PSQI Poor sleep quality: ≥6points	Questionnaire: frequency, amount, intensity, time, and satisfaction with exercise within the past 3 months. The final variable was categorized into: lower (i.e., ≤1 d/week or 2.5h/week) and higher (>1 d/week or 2.5 h/week).	No association after adjustment.
Felden et al.[56] Cross-sectional	Children and adolescents (10 to 19 years). N = 516 Brazil	Questionnaire: Time when going to sleep and waking up on school days. Short sleep was defined as <8 hours.	Questionnaire: no information. The final variable was categorized into "active/ insufficiently active".	No association.
Fusz et al.[35] Cross-sectional	Adults N = 455 Hungary	Questionnaire: Athens Insomnia Scale. Insomnia was defined as 10 points in scale.	Questionnaire: no information. The final variable was PA frequency categorized into: no, never/ rarely/ regularly.	Regular exercise group present lower mean of insomnia score (p = 0.011).
Hartescu et al.[36] Longitudinal	Elderly (65+ years) N = 690 United Kingdom	Questionnaire "Do you ever have problems sleeping?" (i.e., problems getting to sleep and/or staying asleep and/ or waking too early), with five response categories (never, seldom, sometimes, often, all the time)". If the respondent reported one or more sleep problems "often" or "all the time", and if that problem had been experienced within the previous week was considerate insomnia.	Questionnaire: Levels of customary physical activity likely to promote muscle strength, joint flexibility, or stamina were assessed using detailed activity inventories. The amount of walking (purposeful walking, shopping, and recreational walking) in each hour was coded in minutes per day. These were then aggregated in minutes per week. (0/150min walking per week/ ≥min walking per week).	No association
Smagula et al.[37] Longitudinal	Elderly (60+ years) N = 8,265 China	Questionnaire: "On the average, during the last year, how many hours in a day did you sleep (including naps)?' Response options were: 5 h or less; 6h; 7h; 8h; 9h or 10 h or more. Short sleep was defined as <6hours and long sleep as >8hours.	Questionnaire: no information. The final variable categorized PA into: none/ up to 3hours/ 4 hours or more.	No association to short sleep. Up to 3 hours of PA decreased odds of long sleep in 0.74 times (CI 95%: 0.65-0.84) compared to no PA. Similar results to 4 hours or more of PA with odds of 0.83 (CI 95%: 0.26-0.96).

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Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
Wu et al.[38] Cross-sectional	Adults (20+ years) N = 24,190 USA	Questionnaire: "On average, how many hours of sleep do you get in a 24-hour period?" Sleep duration was categorized into: ≤5, 6, 7 (reference), 8, or ≥9h.	Questionnaire: Levels of leisure-time PA were obtained from the following questions: "How often do you do vigorous leisure-time physical activities for at least 10 min that cause heavy sweating or large increases in breathing or heart rate?" "About how long do you do these vigorous leisure-time physical activities each time?" "How often do you do light or moderate leisure-time physical activities for at least 10 min that cause only light sweating or a slight to moderate increase in breathing or heart rate?". "About how long do you do these light or moderate leisure-time physical activities each time?" Based on the quartiles of PA index, the variable is categorized as ≤P25, P25–P50, P50–P75 and >P75.	Compared to P ≤ 25 of PA index, all other percentiles presented lower odds to sleep ≤5 hours: odds P25 = 0.72 (CI 95%: 0.59-0.86) odds P25-P75 = 0.66 (CI 95%: 0.55-0.79) odds P>75 = 0.60 (CI 95%: 0.49-0.79). Compared to P≤25 index of PA, P25-P75 and P>75 index, presented lower odds to sleep 6 hours: odds P25-P75 = 0.82 (CI 95%: 0.73-0.93) odds P>75 = 0.82 (CI 95%: 0.72-0.94) Compared to P≤25 index of PA, P25-P75 and P>75 index, presented lower odds to sleep 8 hours: odds P25-P75 = 0.81 (CI 95%: 0.73-0.90) odds P>75 = 0.82 (CI 95%: 0.73-0.92) Compared to P≤25 index of PA, P25-P75 and P>75 index, presented lower odds to sleep ≥9 hours: odds P25-P75 = 0.70 (CI 95%: 0.58-0.83) odds P>75 = 0.64 (CI 95%: 0.52-078)
Murillo et al.[39] Cross-sectional	Adults (20 to 65 years) N = 9,205 USA	Questionnaire: "How much sleep do you usually get at night, on weekdays or workdays?" Short sleep was defined as ≤6 hours.	Questionnaire: Participants were asked if they participated in any moderate or vigorous recreation activities and if they used a bicycle or walked for transportation. Participants who reported engaging in any recreation PA were asked how many minutes per day in a typical day and how many days per week in a typical week they engaged in each type of activity Recreation PA was categorized based on the physical activity recommendation for weekly activity: inactive (0 minutes/week), insufficiently active (>0 to <150 minutes/week), sufficiently active (≥150 to <300 minutes/week), and highly active (≥300 minutes/week).	No association with recreational PA.
Gong et al.[57] Cross-sectional	Adolescents (12 to 19 years) N = 10,796 China	Questionnaire: "On average night, how many hours of sleep do you get on weekdays and weekend days?" Short sleep was defined as <8 hours.	Questionnaire: no information. Final variable was categorized as: Moderate PA at least 1 day in a week. Strength PA at least 1 day in a week.	Moderate PA was associated to odds 1.16 times higher to adequate sleep compared to no PA group (CI 95%: 1.15-1.17).

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Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
		Questionnaire: Quality: PSQI Poor sleep quality ≥5 points		
Kakinami et al.[58] Cross-sectional	Adolescents and young adults (12 to 24 years) N = 658 Canada	Sleep duration: "During the past month, what time did you usually go to bed at night?" "During the past month, how long has it usually taken you to fall asleep at night?" "During the past month, what time did you usually get up in the morning?" Sleep quantity was represented by the difference between the first and third items, after subtracting out the second item. Sleep quantity was categorized as <7 hours a night, 7-9 hours a night (reference), and ≥9 hours.	Questionnaire: IPAQ (leisure-time). The generated variables were: Total minutes of LPA, MPA and VPA; PA recommendations (≥150 minutes of MPA, ≥75 minutes of VPA.	No association.
Kitano et al.[66] Longitudinal	Workers (age average = 47.9 (10.8)) N = 3,621 Japan	Questionnaire: PSQI` (only question about self-perception of sleep quality). Poor sleep quality: answers bad and very bad.	Questionnaire: IPAQ (leisure time). The final variables were: insufficiently active: engaging in LTPA less than 10 METs-h/week; weekend warrior: engaging in LTPA at least 10 METs-h/week; from 1 or 2 sessions, and regularly active: engaging in LTPA at least 10 METs-h/week; from 3 or more sessions.	Regular activity group presented a odds 0.57 times lower than no practice group (CI 95%: 0.42-0.78).
Sporndly-Nees et al.[40] Longitudinal	Adults (20+ years) N = 5,062 Sweden	Questionnaire: Participants were asked to state how much difficulty they have "falling asleep in the evening,", "waking several times during the night," and "waking too early and having difficulty falling asleep again." A five-point scale was used to score the sleep quality, ranging from score 1 ("none") to 5 ("very severe"). A score of 4 ("severe") or 5 ("very severe") for any of the three items confirmed symptoms of insomnia.	Questionnaire: Leisure-time physical activity was assessed using a four-point scale included the following: 1) spending most of the time watching television, reading, and being sedentary for most of their leisure time; 2)engaging in some physical activity, such as walking and cycling, at least 4 hours per week; 3) participating regularly in swimming, jogging, tennis, and aerobic exercise, for example, for 3 hours per week; and 4) performing vigorous exercise and competition in swimming, running, football, handball, for example, several times per week. The level of physical activity was categorized into three groups (low, medium, and high). Changes in PA from 2000 to 2010 were following: low-low (reference) low-medium medium-low medium-medium medium-high high-low high-medium high-high.	Changes in PA decreased the odds to insomnia compared to group that maintain low Pa in 2000 and 2010 except group high-low odds low-medium: 0.53 (CI 95%: 0.3–0.94) odds low-high: 0.17 (CI 95%: 0.03–0.81) odds medium-low: 0.83 (CI 95%: 0.48–1.42) odds medium-medium: 0.53 (CI 95%: 0.35–0.83) odds medium-high: 0.36 (CI 95%: 0.21–0.64) odds high-low: 1.18 (CI 95%: 0.42–3.3) odds high-medium: 0.37 (CI 95%: 0.21–0.66) odds high-high: 0.3 (CI 95%: 0.16–0.54).

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Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
Zhang et al.[41] Cross-sectional	Adults (45+ years) N = 1,563 China	Questionnaire: PSQI Poor sleep quality ≥6 points.	Questionnaire: no information. The final variable was "exercise".	No exercise group presented odds of 1.79 times higher to poor sleep quality (CI 95%: 1.34-2.40).
Wang et al.[42] Cross-sectional	Adults (18-79 years) N = 21,435 China	Questionnaire: "How many hours do you sleep each night on average?" Sleep duration was categorized into: short sleep: <7 h/day; medium sleep: 7–9 h/day (reference); and long sleep: >9 h/day.	Questionnaire: no information. The final variable was lacking exercise: Participants who did not or seldom (less than once per month).	Lack of exercise group presented odds 1.12 higher to short sleep (CI 95%: 1.02-1.22). Lack of exercise also was associated to long sleep with odds of 1.30 (CI 95%: 1.10-1.55.
Lima & Silva[60] Cross-sectional	Adolescents (14 to 19 years). N = 1,110 Brazil	Questionnaire: "Do you sleep well and feel rested?" The students had five response options: almost never; seldom; sometimes; with relative frequency and almost always. The perception of the quality of sleep was categorized in the appropriate quality of sleep (with relative frequency; almost always) and low quality of sleep (almost never; rarely; sometimes).	Questionnaire: Youth Risk Behaviour Surveillance (YRBSS). "During the last 7 days, on how many days have you been physically active for at least 60 minutes per day? (considering physical activity of moderate intensity and/or vigorous)" The final variable was categorized into: not meet recommendations (0–4 days) and meets recommendations (5 days or more).	No association.
Gubelmann et al.[43] Cross-sectional	Adults (35 to 75 years) N = 2,649 Switzerland	Accelerometer: GENEActive, in wrist by 14 days. Sleep duration: Time with no change in arm angle greater than 5° for 5min or more during predefined nocturnal sleep window (21:00-9:00). Short subjective sleep duration: ≤6 hours Questionnaire: PSQI and Insomnia Severity Index (ISI) Poor sleep quality: PSQI ≥6 points Insomnia: ISI ≥15 points.	Accelerometer: GENEActive, in wrist by 14 days. Participants were split into tertiles of time spent in MVPA and classified as low PA if they were in the first tertile and as high PA otherwise.	No association.
Herring et al.[59] Cross-sectional	Adolescents (12 to 18 years) N = 481 Ireland	Questionnaire: PSQI Poor sleep quality: PSQI ≥6 points.	Questionnaire: Number of days which each participant had accumulated at least 60 min of moderate and vigorous PA during the prior 7 days and for a typical week classified as low (0–2 day/week), moderate (3–4 day/week), or high (5 + day/week).	Moderate (OR = 0.49; 95%CI: 0.29-0.81) and high (OR = 0.53; 95%CI: 0.31-0.92) PA were associated with 51% and 47% lower odds of poor sleep quality.
Štefan et al.[73] Cross-sectional	Undergraduate students (18 to 24 years) N = 2,100 Croatia	Questionnaire: PSQI Poor sleep quality: ≥6 points.	Questionnaire: IPAQ PA was categorized into: sufficiently active: at least 150 min/week of moderate PA ou 75 min/week of Vigorous PA.	Insufficiently active individuals presented odds 1.31 timer higher to poor sleep quality (CI 95%: 1.04-1.64).

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Author, Design	Population, country	Sleep measures	Physical activity measures	Main results
Skarpsno et al.[67] Cross-sectional	Workers (18 to 67 years) N = 650 Denmark	Questionnaire: "How often during the last month did you: have difficulties falling asleep at night? and wake up too early and couldn't get back to sleep?". The response options were: "never", "rarely", "sometimes", "often", and "always" on both questions. Participants answering "often" or "always" on one or both questions were considered to have symptoms of insomnia.	Accelerometry: Actigraph GT3X+, in thigh and the upper back for 6 days. Total physical activity was divided into quartiles to obtain four exposure groups: "very low", "low", "medium", and "high".	No association to total PA or LPA.
Vézina-Im et al.[44] Cross-sectional	Adult women (18 to 44 years) N = 9,749 Canada	Questionnaire: Sleep duration: "How long do you usually spend sleeping each night?" Short sleep was defined as <7 hours. Sleep quality: "How often do you have trouble going or staying asleep?"; "How often do you find your sleep refreshing?" "How often do you find it difficult to stay awake when you want to?" These three questions generated a score of sleep quality.	Questionnaire: "Have you done any of the following (walking for exercise, gardening or yard work, swimming, bicycling, popular or social dance, home exercises, ice hockey, ice skating, in-line skating or rollerblading, jogging or running, golfing, exercise class or aerobics, downhill skiing or snowboarding, bowling, baseball or softball, tennis, weight-training, fishing, volleyball, basketball, soccer, any other, no physical activity) in the past 3 months?" The final variable was exercise (yes/no).	No association.

PA = Physical activity; LPA = Leisure physical activity; MVPA = Moderate to vigorous physical activity; MET = Equivalent metabolic; PSQI = Pittsburgh Sleep Quality Index; IPAQ = International Physical Activity Questionnaire; Sd = standardized deviation.