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Complete List of Authors:	Bjornsdottir, Erla; Reykjavik University Thorarinsdottir, Elin; Heilsugasla hofuoborgarsvaoisins; University of Iceland, Faculty of medicine Lindberg, Eva ; Uppsala University, Department of Medical Sciences: Respiratory, Allergy and Sleep Research Benediktsdottir, Bryndis; University of Iceland, Faculty of Medicine; Landspitali haskolasjukrahus, Department of Sleep Franklin, Karl; Umea Universitet, Department of Surgical and Perioperative Sciences Jarvis, Debbie; Imperial College London School of Public Health, Population Health and Occupational Disease, National Heart and Lung Institute; Imperial College London, MRC-PHE Centre for Environment and Health Demoly, Pascal ; University Hospital of Montpellier, France and Sorbonne Universités, University of Montpellier - Inserm UMR UA11 Perret, Jennifer; The University of Melbourne Melbourne Medical School Garcia Aymerich, Judith; ISGlobal, Centre for Research in Environmental Epidemiology (CREAL); Universitat Pompeu Fabra Dorado-Arenas, Sandra; Hospital Galdakao-Usansolo, Pulmonology Department Heinrich, Joachim; Ludwig Maximilians University Munich, Institute and Clinic for Occupational, Social and Environmental Medicine; The University of Melbourne Melbourne Medical School, Allergy and Lung Health Unit, Melbourne School of Population and Global Health Torén, Kjell; Goteborgs universitet Institutionen for medicin, Occupational and Environmental Medicine Garcia Larsen, Vanessa; Johns Hopkins University Bloomberg School of Public Health, 17Program in Human Nutrition, Department of International Health Jögi, Rain; Tartu University Hospital, The Lung Clinic Gislason, Thorarinn; University of Iceland, Faculty of Medicine; Landspitali haskolasjukrahus, Department of Sleep Janson, Christer; Uppsala University, Department of Medical Sciences: Respiratory, Allergy and Sleep Research
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The longitudinal association of physical activity with symptoms of insomnia, sleep duration and daytime sleepiness - A European population-based study

Erla Bjornsdottir[1*], Elin Helga Thorarinsdottir [2,3*], Eva Lindberg[4], Bryndis Benediktsdottir[3,5] Karl A Franklin[6], Deborah L Jarvis[7,8], Pascal Demoly[9], Jennifer Perret[10], Judith Garcia-Aymerich[11,12], Sandra Dorado-Arenas[13], Joachim Heinrich[14,15], Kjell Toren[16], Vanessa Garcia Larsen[17], Rain Jogi[18] Thorarinn Gislason[3,5**], Christer Janson[4**]

*Co-first authors, ** Co-senior author

Affiliations:
[1] University of Reykjavik, Iceland
[2] Primary Health Care of the Capital Area, Reykjavik, Iceland
[3] Faculty of Medicine, University of Iceland, Reykjavik, Iceland
[4] Department of Medical Sciences: Respiratory, Allergy and Sleep Research, Uppsala University, Uppsala, Sweden
[5] Department of Sleep, Landspitali - The National University Hospital of Iceland, Reykjavik, Iceland.
[6] Department of Surgical and Perioperative Sciences, Surgery, Umeå Univeristy, Umeå,Sweden
[7] Population Health and Occupational Disease, National Heart and Lung Institute, Imperial College London, London, UK
[8] MRC-PHE Centre for Environment and Health, Imperial College London, London, UK
[9] University Hospital of Montpellier, Montpellier, France and IDESP, University of Montpellier - Inserm UMR UA11
[10] University of Melbourne, Melbourne, Victoria, Australia.
[11] ISGlobal, Centre for Research in Environmental Epidemiology (CREAL), Barcelona, Spain
[12] Universitat Pompeu Fabra (UPF), Barcelona, Spain
[13] Pulmonology Department, Galdakao-Usansolo Hospital, OSI Barrualde-Galdakao (Osakidetza), Biscay, Spain
[14] Institute and Clinic for Occupational, Social and Environmental Medicine, University Hospital, LMU Munich, Comprehensive Pneumology Center (CPC-M) Munich, German Center for Lung Research (DZL)
[15] Allergy and Lung Health Unit, Melbourne School of Population and Global Health, The University of Melbourne, Melbourne, Australia
[16] Department of Occupational and Environmental Medicine, Institute of Medicine, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden
[17] Program in Human Nutrition, Department of International Health, The Johns Hopkins Bloomberg School of Public Health, Baltimore, USA.
[18] The Lung Clinic, Tartu University Hospital, Tartu, Estonia.

Correspondant author:
Erla Bjornsdottir
erlabjo@gmail.com
00354-8608009

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Abstract:

Objectives: To explore the relationship of physical activity during the past 10 years with insomnia, daytime sleepiness and estimated short or long sleep duration among middle aged adults.

Design: Population-based, multi-centre cohort study.

Setting: 21 centres in 9 European countries.

Methods: Included were 4339 participants in the third follow-up of the European Community Respiratory Health Survey (ECRHS III) who answered questions on physical activity at baseline (ECRHS II) and questions on physical activity, insomnia symptoms, sleep duration and daytime sleepiness at follow up (ECRHS III). Physical activity was assessed both in ECRHS III and 10 years before. Participants reported that they exercised with a frequency of at least two or more times a week for one hour a week or more were classified as being physically active. Change in activity status was categorised into four groups: persistently non-active, became inactive, became active and persistently active.

Main outcome measures: Insomnia, sleep time and daytime sleepiness in relation to physical activity.

Results: Altogether, 37% of participants were persistently non-active, 25% were persistently active, 20% became inactive and 18% became active from baseline to follow up. Participants that were persistently active were less likely to report difficulties initiating sleep (OR 0.60 (95% CI 0.45-0.78)), short sleep duration of ≤6 h/night (OR 0.71 (95% CI 0.59-0.85) and long sleep of (≥9 h/night (OR 0.53 (95% CI 0.33-0.84)) than persistently non active subjects after adjusting for age, sex, BMI, smoking history, and study centre. Daytime sleepiness and difficulties maintaining sleep were not related to physical activity.

Conclusion: Physically active people have a lower risk of insomnia symptoms and extreme sleep duration, both long and short.

Strengths and limitations of this study:

- The longitudinal study design, with the exposure (physical activity) measured 10 years before the outcome (sleep outcomes) allows testing the directionality of the association.
- Data was collected using standardized and validated procedures and instruments, increasing internal validity.
- Data was obtained from 9 European countries, increasing external validity of our findings.
- One limitation of our study is that sleep variables are only available at the follow-up, precluding testing their role on baseline physical activity.
- Insomnia symptoms, sleep length and daytime sleepiness were obtained from questionnaire and no doctor diagnosis or objective assessments were available.

Introduction

Disturbed sleep is common in the general population and impacts health and quality of life.[1-3] Chronic sleep disturbances are associated with cardiovascular disease, metabolic dysfunction, psychiatric disorders, and increased mortality.[4-6]

Regular exercise is associated with better health and several studies suggest that physical activity (PA) is beneficial on sleep and may improve symptoms of chronic insomnia.[7-10] It is, however, unclear how large these benefits are and which factors moderate these benefits.[11] The positive association between PA and sleep might be subject to multiple moderating factors such as gender, age, BMI, fitness level, general health and the characteristics of the exercise. Therefore, sleep and PA probably influence each other through complex, reciprocal interactions including multiple physiological and psychological pathways.[7]

There is evidence that more PA is associated with less daytime sleepiness.[12-17] Cross-sectional studies have shown that low PA is associated with increased likelihood of excessive daytime sleepiness (EDS)[14-16] and that subjects participating in exercise are less likely to have EDS.[12 17] In the elderly, increasing PA by doing home exercises has been shown to improve EDS and reduce the prevalence of insomnia symptoms[13] and another study showed that increasing PA protected women from future insomnia.[18] Other studies have contradictory findings. In an epidemiological study of 4.405 Koreans, daytime sleepiness was more common among those in the top quartile of PA compared to those in the lowest quartile group.[19] Among patients with obstructive sleep apnoea increased PA was associated with lower disease severity and 28% decrease in EDS.[20] The daily association between PA and sleep duration was described in 2021 based on a systemic review and meta-analysis on 33 peer-reviewed papers showing that the night following an increased PA there was a lower total sleep time.[21]

There is a lack of epidemiological data from long-term follow-up of large cohorts studying the association of PA to sleep length, daytime sleepiness, and insomnia symptoms. Previous research on physical activity and sleep-related outcomes has several important limitations. Most studies are cross-sectional or with a short follow-up, preventing to elucidate if increased physical activity improves sleeping outcomes or reduced physical activity is a consequence of sleep problems. Finally, no studies have tested at the same time the effect of physical activity on sleep length, daytime sleepiness, and insomnia symptoms. Therefore, the aim of the present study was to assess the interrelationship between physical activity based on frequency, duration and intensity and symptoms of insomnia, self-reported sleep duration and daytime sleepiness among middle-aged subjects from 21 centres in 9 countries at two time periods 10 years apart, giving important longitudinal follow up data.

Material and methods

Patient and Public Involvement:

We studied participants in the second and third follow-up of the European Community Respiratory Health Survey (ECRHS II and III, www.ecrsh.org), an international, population-based, multicentre cohort study of asthma and allergy, which was first performed in 1990. Detailed descriptions of the methods for ECRHS I and ECRHS II have been published elsewhere.[22 23] Briefly, participating centres first randomly selected samples of 20 to 44-year-old subjects. Participants completed a short postal questionnaire about asthma and asthma-like symptoms and from those who responded, a random sample was selected to undergo a more detailed clinical examination. In ECRHS II, subjects who had participated in the clinical phase of ECRHS I (performed between 1991 – 1994) were invited to participate in follow-up. The clinical phase of ECRHS II was performed between 1998 to 2002. ECRHS III is the second follow-up and was performed from February 2011 to January 2014.[22-24] The present study is based on data from ECRHS II and III (see figure 1 for flowchart). Ethical approval for the study from local research ethics committees and written consent from participants were obtained.

Health, habits, and measurements

Subjects answered the core ECRHS questionnaires which included questions on lifestyle, respiratory symptoms, smoking history, and general health. Current smokers were defined as those who smoked tobacco regularly during the last month. Former smokers were defined as smokers who denied having smoked regularly for a month prior to the examination. Those who reported no regular smoking at or prior to the examination were defined as never smokers. Height and weight were measured, and body mass index (BMI) was calculated.[24]

Assessment of physical activity

Physical activity was assessed in ECRHS II and III using questionnaire.[22] Participants were asked how often and for how many hours per week they usually exercised so that they got out of breath or became sweaty. Participants who exercised two or more times a week during at least 1 hour a week were classified physically active. Change in activity status from baseline to follow up was categorised into four PA groups: persistently non-active (non-active at both baseline and follow up), became inactive (active at baseline and non-active at follow up), became active (non-active at baseline and active at follow up) and persistently active (active at both baseline and follow up).

Sleep questionnaires and measurements

Sleep-related symptoms were assessed by using the Basic Nordic Sleep Questionnaire[25], where participants were asked about frequency of insomnia symptoms. Answers were on a scale of 1 – 5: (1) never or very seldom, (2) less than once a week, (3) once to twice a week, (4) three to five times a week, (5) every day or almost every day of the week. Insomnia symptoms were defined using answers to three questions from the Basic Nordic Sleep Questionnaire "I have difficulties falling asleep at night" (difficulties initiating sleep), "I wake up often during the night" (difficulties maintaining sleep) and "I wake up early in the morning and can't fall back asleep" (early morning awakenings). Those who reported those symptoms of insomnia ≥3 times a week (scores 4 and 5) were considered to have the corresponding insomnia subtype. Daytime sleepiness was evaluated using the Epworth Sleepiness Scale, a brief questionnaire that measures daytime sleepiness based on the likelihood of falling asleep in eight different situations.[26] Participants with Epworth sleepiness scale score >10 were considered to have EDS. Participants answered the question: how much sleep do you estimate that you get on average each night? They were classified as short sleepers (≤6 hours/night), normal sleepers (6–9 hours/night) and long sleepers (≥9 hours/night) according to their answers.

Statistical analysis

Data are presented as number and percentage or mean ±SD, depending on distribution. For bivariate analysis, the χ^2 test and one-way analysis of variance were used for nominal and continuous variables. Logistic regression was used for multivariable analyses to estimate the association between physical activity and sleep related outcomes after adjusting for potential confounders such as sex, age, BMI and smoking status. STATA V.16 was used for all statistical analyses.

Results

Participants and level of physical activity

From a total of 5.850 participants in ECRHS II, we excluded those with missing data and included a total of 4.339 participants (48% men), see Figure 1. From baseline to 10 years later, 36.9% of participants were persistently non-active, 17.9% became physically active at follow-up, 20.3% of participants became inactive 24.9% were persistently active (Table 1).

Table 1. Characteristics and general health of the participants by the level of physical activity

	Persistently non-active	Became inactive	Became active	Persistently active	p-value
General characteristics					
N, %	1601 (36.9)	881 (20.3)	775 (17.9)	1082 (24.9)	
Men, %	44.3	49.0	46.8	53.7	**<0.001**
Age, years	55.0 ± 7.2	54.5 ± 7.1	53.4 ± 7.2	53.7 ± 7.2	**<0.001**
Body mass index, kg/m^2	27.6 ± 5.2	27.1 ± 4.9	27.1 ± 4.8	27.0 ± 4.4	**0.007**
Currently working, %	82.7	85.8	88.9	90.4	**<0.001**
Smoking history					
Never, %	42.4	43.4	44.3	47.6	**<0.001**
Former, %	34.4	39.8	37.5	40.0	
Current, %	23.2	16.9	18.2	12.4	

There were geographical differences in the level of physical activity between the ECRHS countries (Figure 2). Participants in Norway were most likely to be persistently active, while participants in Spain, followed by Estonia, were most likely to be persistently non-active (Figure 2).

General characteristics and health

Persistently active participants were more often men, they were younger, and they had slightly lower BMI (Table 1). They were also less likely to be current smokers and more likely to be currently working (Table 1).

Insomnia symptoms

In unadjusted analysis, there was a significant difference in reporting difficulties initiating sleep, early morning awakenings and any insomnia symptom where those persistently active were least likely to report these symptoms. Also, persistently active subjects were the least likely to report two and three insomnia symptoms (Table 2).

Table 2. Insomnia symptoms, sleep duration and daytime sleepiness by level of physical activity.

	Persistently non-active (n=1601)	**Became inactive** (n=881)	**Became active** (n=775)	**Persistently Active** (n=1082)	p-value
Insomnia symptoms					
Difficulties initiating sleep (%)	15.4	14.0	11.7	8.2	**<0.001**
Difficulties maintaining sleep (%)	31.9	32.1	33.0	28.5	0.128
Early morning awakenings (%)	18.2	18.3	15.0	13.2	**0.002**
Any insomnia symptom (%)	41.0	41.5	39.5	34.9	**0.006**
Numbers of insomnia symptoms					
None (%)	58.4	58.2	61.0	64.9	**0.001**
One (%)	23.2	25.2	24.0	23.8	
Two (%)	11.9	10.6	10.0	7.8	
Three (%)	6.6	6.1	5.1	3.6	
Sleep duration					
Sleep time (hours)	6.8 ± 1.1	6.8 ± 1.0	6.9 ± 1.0	6.9 ± 0.9	0.234
Sleep time, %					**<0.001**
Short sleepers (≤ 6 hours)	35.9	31.9	20.7	26.9	
Normal sleepers (6 – 9 hours)	59.2	64.6	66.9	70.9	
Long sleepers (≥ 9 hours)	4.9	3.5	3.4	2.2	
Daytime sleepiness					
Epworth sleepiness scale score	6.8 ± 4.1	7.2 ± 4.1	6.9 ± 4.1	6.9 ± 3.8	0.106
Epworth sleepiness scale score >10 (%)	17.2	19.4	17.7	15.6	0.176

Data are presented as mean ± standard deviation or % where indicated. Significant differences are in bold ($p<0.05$). *p-value from Pearson´s chi-square test (numerical variables) and one-way analysis of variance (continuous variables).

After adjusting for age, sex, BMI, smoking history and study centre, this negative association remained for difficulties initiating sleep (OR 0.58 (0.42-0.77)), any insomnia symptom (0.78 (0.65-0.94) and reporting two (OR 0.60 (0.43-0.82) and three (OR 0.63 (0.41-0.98) insomnia symptoms (Table 3). Additionally, in adjusted analysis, persistently active subjects were significantly less likely to report difficulties initiating sleep (OR 0.80 (0.66-0.97) (Table 3).

Table 3. Independent association between the level of physical activity and medical disorders, insomnia symptoms, daytime sleepiness and sleep duration expressed as adjusted* odds ratios (95% CI) with the persistently non-active group as reference.

	Became inactive (n=881)	**Became active** (n=775)	**Persistently active** (n=1082)
Insomnia symptoms			
Difficulties initiating sleep	0.97 (0.75-1.25)	0.82 (0.62-1.08)	**0.58 (0.42-0.77)**
Difficulties maintaining sleep	0.96 (0.80-1.17)	1.04 (0.85-1.27)	**0.80 (0.66-0.97)**
Early morning awakenings	1.09 (0.87-1.38)	0.86 (0.63-1.03)	0.80 (0.63-1.03)
Any insomnia symptom	1.02 (0.85-1.22)	0.95 (0.78-1.14)	**0.78 (0.65-0.94)**
Numbers of insomnia symptoms			
One	1.07 (0.86-1.32)	0.99 (0.79-1.24)	0.91 (0.74-1.12)
Two	0.89 (0.66-1.20)	0.86 (0.63-1.17)	**0.60 (0.43-0.82)**
Three	1.09 (0.74-1.59)	0.94 (0.62-1.42)	**0.63 (0.41-0.98)**
Daytime sleepiness			
Epworth sleepiness scale score >10	1.17 (0.94-1.47)	1.00 (0.78-1.27)	0.87 (0.69-1.10)
Sleep duration			
Short sleepers (≤ 6 hours)	0.89 (0.73-10.7)	0.85 (0.69-1.03)	**0.71 (0.58-0.85)**
Normal sleepers (6-9 hours)	1.18 (0.98-1.42)	**1.21 (1.00-1.47)**	**1.55 (1.29-1.87)**
Long sleepers (≥ 9 hours)	0.74 (0.47-1.17)	0.84 (0.53-1.33)	**0.48 (0.28-0.80)**

*Adjusted for age, sex, BMI, smoking history and center. Significant differences are in bold.

Sleep duration and daytime sleepiness

In unadjusted analysis, there was a significant difference in short and long sleep duration between levels of activity. Those who were persistently active were most likely to be normal sleepers and the persistently non-active were least likely (70.9% vs. 59.2% respectively) (Table 2). After adjusting for age, sex, BMI, smoking history and study centre, these results remained significant for persistently active subjects. They were significantly more likely to be normal sleepers (OR 1.55 (1.29-1.87)) and significantly less likely to be short sleepers (OR 0.71 (0.58-0.85)) or long sleepers (0.48 (0.28-0.80)) (Table 3). Additionally, those who became active were more likely to be normal sleepers than those persistently non-active (OR 1.21 (1.00-1.47) (Table 3).

However, there was not a significant association between the mean Epworth sleepiness scale score or percentage with Epworth sleepiness scale score >10 and level of physical activity (Tables 2 and 3).

Discussion

The main results of this study were that participants who reported being physically active at the start and end of a 10 year follow up period were less likely to report insomnia symptoms at the follow-up. We also found that subjects that are persistently active are more likely to sleep the recommended 6-9 hours. This association remained statistically significant after adjusting for sex, age, smoking history, and BMI.

Our results are in line with previous studies that have shown a beneficial effect of physical activity on symptoms of insomnia (9, 10), but the current study additionally shows the importance of consistency in exercise over time because the association was lost in initially active subjects who became inactive. A recent meta- analysis examining the effects of acute and regular exercise on a range of sleep variables showed that acute exercise (less than one week of exercise) has a small beneficial effect on many objective measures of sleep such as total sleep time, symptoms of insomnia and sleep quality.[7] Furthermore, this meta-analysis found greater benefits for regular exercise on both subjective and objective sleep parameters over time. Regular exercise had small beneficial effects on total sleep time and sleep efficiency, small-to-medium beneficial effects on sleep onset latency, and moderate beneficial effects on sleep quality.[7]

There are two recent systematic reviews and meta-analysis on the effects of PA on sleep[7] and insomnia[9] both substantially reviewing the same randomized controlled studies. Banno *et al*. included nine studies with a total of 557 participants.[7] The majority of participants exercised 3 times or less per week and follow-up was 4 months or shorter in all studies except one. Their conclusion was that exercise could improve sleep, but higher quality research was needed.[7] Five studies on insomnia and additionally six on insomnia symptoms showed shorter sleep latency and higher sleep efficacy, but the authors also acknowledged the small size of the literature and severe methodological limitations often based on selection bias.[9] Most previous studies are also cross-sectional which can also be considered a limitation.

This study has a long follow up period (10 years) and indicates strongly that consistency in physically activity might be an important factor to optimize sleep duration and reduce symptoms of insomnia. Most other studies have had a much shorter follow up period[7] which makes it more difficult to assess consistency in activity over time.

Our results indicate that those who are consistent in physical activity are also less likely to be both short (<6h) and long sleepers (>9h). Those who are physically active in general are also more likely to engage in a healthier lifestyle[27] which also can have an effect on sleep. Lifestyle factors such as healthy diet and physical activity are probably a part of a phenotype that characterizes those individuals who are generally engaged in a healthy lifestyle. A recent review highlighted the importance of focusing on the combination of sleep, diet and exercise when exploring healthy longevity.[28]

The three groups reporting low physical activity in either ECRHS survey or at both time points are all reporting very similar prevalence of insomnia symptoms, extreme sleep length and daytime sleepiness. This is somewhat surprising, especially that those who are active at the follow-up but were not at baseline do have very similar symptom profile as those who were inactive at both surveys. Our study found a consistency in a behaviour like physical activity for more than a decade is strongly related to less insomnia and more "normal" sleep length. The important information concerning "the healthy phenotype" would be missed if the physical activity data were available only at baseline or at follow-up but not at both time points. Under these circumstances physical activity data would only have shown very limited association with sleep.

In a recent review based on 22 randomized controlled trials on the effects of regular exercise (lasting at least 2 months on a regular basis) on self-reported sleep quality, insomnia and daytime sleepiness, it was found that regular physical activity improved subjective sleep quality, insomnia severity, and daytime sleepiness as measured only with the Epworth sleepiness scale.[29] These results regarding insomnia symptoms are in line with our study but the results on daytime sleepiness differ from our results. The reason for this discrepancy could be due to different study populations since there were only two studies in this review that measured daytime sleepiness using the Epworth sleepiness scale, one study assessed this among the elderly, 60 years and older[13] and the other among overweight and obese men.[30] Another recent review of 32 randomized control trials on the effects of exercise on improving sleep disturbances showed that exercise is beneficial in improving sleep quality, symptoms of insomnia, restless legs, sleep apnoea and daytime sleepiness. However, exercise only had significant effects on sleepiness if it had lasted for more than 12 weeks while the exercise period did not matter in regards of the association to sleep quality and insomnia symptoms.[31]

Another recent study showed that high or increasing levels of physical activity could protect women from future insomnia.[18] Therefore, exercise seems to have a stronger association with sleep quality and insomnia than with sleepiness, which is in line with our results. However almost all previous studies, have the limitation that the definition of sleepiness is limited to the estimate the likelihood of falling asleep but not the general feeling of sleepiness, that we have shown is also an important part of sleepiness.[32 33] Another recent review exploring the associations of exercise, sleep and cognitive function among older adults showed interesting results. Physical activity is associated with improved cognitive function but the association of sleep and cognitive function seems to be U-shaped, as too much or too little sleep is negatively associated with cognitive function.[34] It would therefore be interesting for future studies to explore how cognitive function is affected by the association of physical activity and sleep.

This study has several strengths such as the population-based nature, the longitudinal study design and the large sample collected in the same manner at many centres in 9 different countries. Another strength is the use of standardized and validated procedures and instruments. The long follow up period is also a strength since data on physical activity is collected ten years apart and subjects are categorized according to change in physical activity. This study is however not without limitations. It is not possible to know whether those who are active at both timepoints have been continuously physically active throughout the study period or only at these two timepoints. Another limitation of our study is that sleep variables are only available at the follow-up, and we only have information on insomnia symptoms but not the diagnosis of insomnia disorder. Sleep length and daytime sleepiness are also based on subjective data. Another limitation is that physical activity was only measured using a questionnaire. Also, the questions included only vigorous physical activity and the effect of moderate or low intensity activity could not be tested.

In conclusion, physical activity over time is associated with lower prevalence of insomnia symptoms and a more likelihood of sleeping the recommended 6-9 hours per night.

Ethical statement:

All participants participated voluntarily in the study. Ethical approval for the study from local research ethics committees and written consent from participants were obtained.

Contributors EB and EHT drafted the paper, participated in designing the study and performed the statistical analysis. CJ and EL designed the study, participated in manuscript preparation and reviewed the paper on several stages. CJ also contributed to the statistical analysis. BB participated in data collection and reviewing the paper. KF, DLJ, PD, JP,JG-A, SDA,JH, KT, VGL, RJ contributed to the statistical analysis and reviewed the paper. TG and CJ are the correspondence author, and he designed the study, participated in manuscript preparation and reviewed the paper on several stages.

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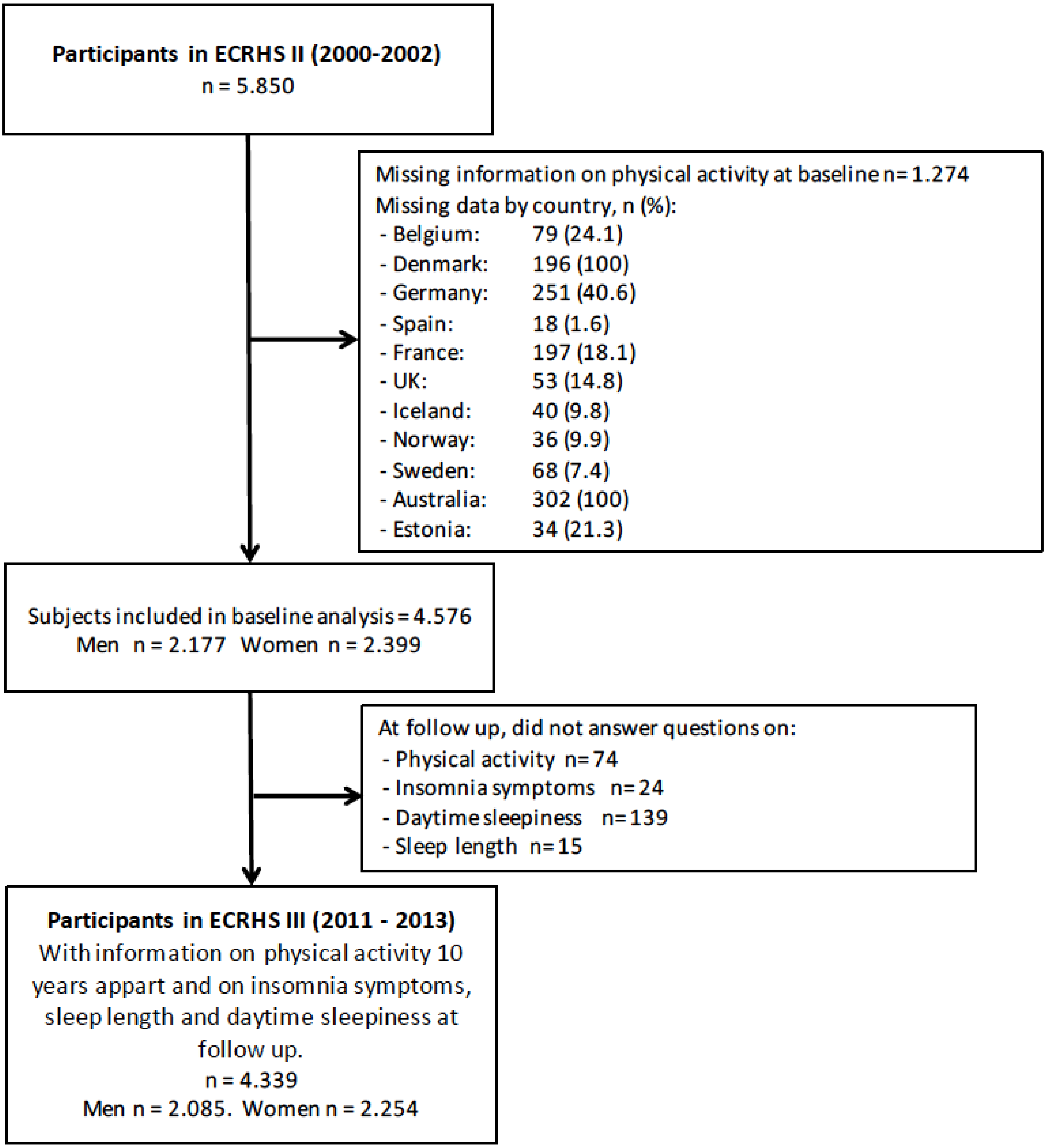
Figure 1. Flow chart of the study population in the European community health survey (ECRSH)



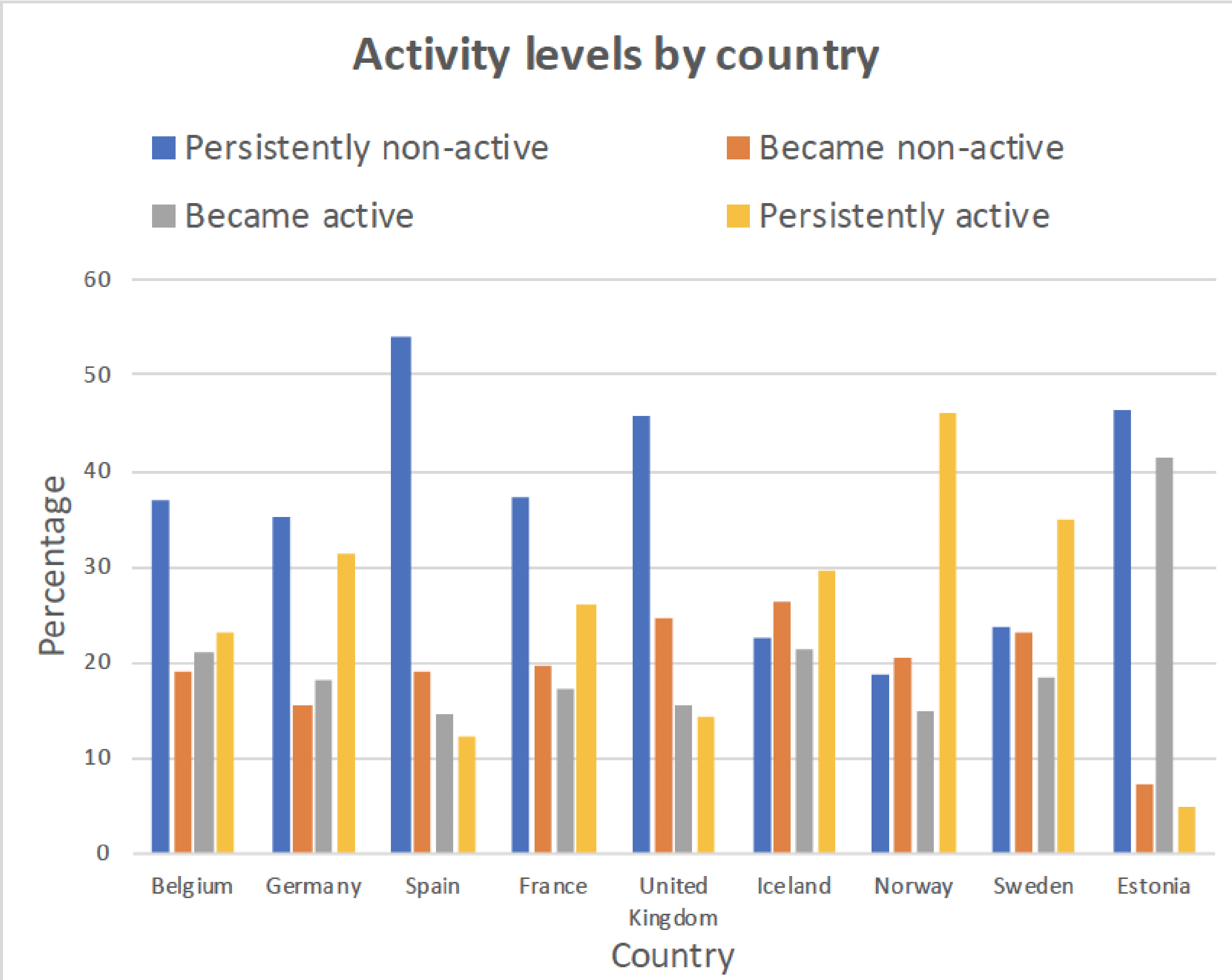


Figure 2. Activity levels by country

Ethical approvals over lifetime of ECRHS 1,2, 3

Committee name and approval number

Genetics	**Centre Name & Country**	**ECRHS 1**	**ECRHS 2**	**ECRHS 3**
N	Australia, Melbourne	Alfred Hospital Ethics Review Committee 24 / 91	The Alfred Healthcare Group Ethics Committee 24/91. (amendment)	Monash University Human Research Ethics Committee Project # CF11/1818-2010001012
N	Belgium, South Antwerp and Antwerp City	Not available	Not available	Comité voor Medische Ethiek UZA/UA 11/41/288 – UA
N	Denmark, Aarhus	Unable to find	N/A	De Videnskabsetiske Komiteer for region Midtjylland. M-20110106
Y	Estonia, Tartu	Cannot get the info, text redacted.	Research Ethics Committee of the University of Tartu (UT REC) 60/3-1998	Research Ethics Committee of the University of Tartu (UT REC) 209T-17 and 225/M-24

N	France, Paris	Comité Consultatif National d'Ethique Pour les Sciences de la Vie et de la Santé, Section Technique, N/réf.AB/GM/ 91-298 - 19/07/91. INSERM- Biomedical research authorization n°91020 (01/03/91), Approval of the Commission Nationale Informatique et Liberté (CNIL (protection of the data) 05/08/91	Comité consultatif de protection des personnes dans la recherche biomédicale de Bichat- Claude Bernard". 17/11/1999	Etude ECRHS III: promotion CHU de Grenoble. Ethical approval CPP Sud est V 4 mars 2011. Approval Ministry of Health AFSSAPS n°B110053-70.
Y	France, Grenoble	Comité Consultatif National	Comité consultatif de protection des	Etude ECRHS III: promotion CHU

		d'Ethique Pour les Sciences de la Vie et de la Santé, Section Technique, N/réf.AB/GM/ 91-298 - 19/07/91. INSERM-Biomedical research authorization n°91020 (01/03/91), Approval of the Commission Nationale Informatique et Liberté (CNIL (protection of the data) 05/08/91	personnes dans la recherche biomédicale de Bichat-Claude Bernard". 17/11/1999	de Grenoble. Ethical approval CPP Sud est V 4 mars 2011. Approval Ministry of Health AFSSAPS n°B110053-70.
N	France, Montpellier	Comité Consultatif National d'Ethique Pour les Sciences de la Vie et de la	Comité consultatif de protection des personnes dans la recherche	Etude ECRHS III : promotion CHU de Grenoble. Ethical approval CPP Sud est V 4

		Santé, Section Technique, N/réf.AB/GM/ 91-298 - 19/07/91. Inserm INSERM-Biomedical research authorization n°91020 (01/03/91), Approval of the Commission Nationale Informatique et Liberté (CNIL (protection of the data) 05/08/91	biomédicale de Bichat-Claude Bernard". 17/11/1999	mars 2011. Approval Ministry of Health AFSSAPS n°B110053-70.
N	France, Bordeaux	Comité Consultatif National d'Ethique Pour les Sciences de la Vie et de la Santé, Section Technique,	Comité consultatif de protection des personnes dans la recherche biomédicale de Bichat-	- Etude ECRHS III : promotion CHU de Grenoble. Ethical approval CPP

		N/réf.AB/GM/ 91-298 - 19/07/91. Promotion) Inserm INSERM-Biomedical research authorization n°91020 (01/03/91), Approval of the Commission Nationale Informatique et Liberté (CNIL (protection of the data) 05/08/91	Claude Bernard". 17/11/1999	Sud est V 4 mars 2011. Approval Ministry of Health AFSSAPS n°B110053-70.
Y	Germany, Hamburg	Ethikkommission der Ärztekammer Schleswig-Hollstein, Positive Votum, no number	Ethikkommission der Bayerischen Landesärztekammer (Positive Votum: Nr. 00079)	Ethikkommission der Bayerischen Landesärztekammer (Positive Votum: 10015

Y	Germany, Erfurt	Ethikkommission der Medizinischen Akademie Erfurt, Positive Votum, no number	Ethikkommission der Bayerischen Landesärztekammer (Positive Votum: Nr. 00079)	Ethikkommission der Bayerischen Landesärztekammer (Positive Votum: 10015
N	Iceland, Reykjavik	?	?	National Bioethics committee of Iceland VSN-11-121-S3
N	Italy, Pavia	No formal ethics committee- data unavailable	Ethics Committee of Internal Medicine and Medical Therapy Department, Pavia University (The approval was reported in the memorandum n. 4/1999)	Ethics Committee of IRCCS ''San Matteo'' Hospital Foundation, University of Pavia, Pavia (approval number 24215/2011)
N	Italy, Turin		?	?
N	Italy, Verona	N/A	N/A	"Comitato Etico per la sperimentazione dell'Azienda Ospedaliera Universitaria

				Integrata di Verona", N. Prog. 1393
N	Netherlands, Groningen	?	?	?
N	Netherlands, Bergen-op-zoon	?	?	?
N	Netherlands, Geleen	?	?	?
Y	Norway, Bergen	The Regional Committee for Medical and Health Research Ethics West Norway Approval number: 42.91	The Regional Committee for Medical and Health Research Ethics West Norway Approval number: 149.2000	Regional Ethics Committee West Norway 2010/759
	Barcelona, Spain	JA cannot find	Ethics Committee of the Parc de Salut Mar, Barcelona (Comité del etico d'investigacion clínica (CEIC)-Parc de Salut	Ethics Committee of the Parc de Salut Mar, Barcelona (Comité del etico d'investigacion clínica (CEIC)-Parc de Salut Mar, Barcelona (Approval

			Mar, Barcelona) (Approval number 98/835/I)	number) 2009/3500/1
Y	Spain, Galdakao	JA cannot find	Ethics Committee of the Parc de Salut Mar, Barcelona (Comité etic d'investigacio clínica (CEIC)-Parc de Salut Mar, Barcelona) Approval number? 98/835/I)	Ethics Committee of the Parc de Salut Mar, Barcelona (Comité etic d'investigacio clínica (CEIC)-Parc de Salut Mar, Barcelona (Approval num) 2009/3500/1
Y	Spain, Albacete	Ja cannot find	Ethics Committee of the Parc de Salut Mar, Barcelona (Comité etic d'investigacio clínica (CEIC)-Parc de Salut Mar, Barcelona) Approval number? 98/835/I)	Ethics Committee of the Parc de Salut Mar, Barcelona (Comité etic d'investigacio clínica (CEIC)-Parc de Salut Mar, Barcelona (Approval number) 2009/3500/1

Y	Oviedo, Spain	Ja cannot find	Ethics Committee of the Parc de Salut Mar, Barcelona (Comité etic d'investigacio clínica (CEIC)-Parc de Salut Mar, Barcelona) Approval number? 98/835/I)	Ethics Committee of the Parc de Salut Mar, Barcelona (Comité del etico d'investigacion clínica (CEIC)-Parc de Salut Mar, Barcelona (Approval number) 2009/3500/1
Y	Huelva, Spain	JA cannot find-Manolis?	Ethics Committee of the Parc de Salut Mar, Barcelona (Comité etic d'investigacio clínica (CEIC)-Parc de Salut Mar, Barcelona) Approval number? 98/835/I)	Ethics Committee of the Parc de Salut Mar, Barcelona (Comité del etico d'investigacion clínica (CEIC)-Parc de Salut Mar, Barcelona (Approval number) 2009/3500/1
Y	Basle, Switzerland	Unavailable	Überregionale Ethikkommission für Klinische	Swiss Academy of Sciences-Number not available

			Forschung (UREK M175/99 123/00	
N	Gothenburg, Sweden	Regional Ethical Review Board in Uppsala. 1990/257 and 1991/33	Regional Ethical Review Board in Uppsala. 1999/313	Regional Ethical Review Board in Uppsala. 2010/432
Y	Uppsala, Sweden	Regional Ethical Review Board in Uppsala. 1990/257 and 1991/33	Regional Ethical Review Board in Uppsala. 1999/313	Regional Ethical Review Board in Uppsala. And the number of the decision is 2010/432
Y	Umea	Regional Ethical Review Board in Uppsala. 1990/257 and 1991/33	Regional Ethical Review Board in Uppsala. 1999/313	Regional Ethical Review Board in Uppsala. 2010/432
Y	Ipswich, UK	Ipswich District Hospital Ethics Committee	Suffolk	NRES committee London-Stanmore REC Ref: 11/LO/0965
Y	Norwich, UK	Norfolk and Norwich Hospital Ethics Committee	Norfolk	NRES committee London-Stanmore REC Ref: 11/LO/0965

N	Cambridge, UK	Y	N	N
N	Caerphilly, UK	?	?	NRES committee London-Stanmore REC Ref: 11/LO/0965

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	5-6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-8
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8
Bias	9	Describe any efforts to address potential sources of bias	4, 12
Study size	10	Explain how the study size was arrived at	8, fig 1
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7-8
		(*b*) Describe any methods used to examine subgroups and interactions	7-8
		(*c*) Explain how missing data were addressed	8, fig 1
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	8, fig 1

(*e*) Describe any sensitivity analyses

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8, fig 1
		(b) Give reasons for non-participation at each stage	8, fig 1
		(c) Consider use of a flow diagram	Fig 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8
		(b) Indicate number of participants with missing data for each variable of interest	Table 1
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	6
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	*8-9*
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	*N/A*
		Cross-sectional study—Report numbers of outcome events or summary measures	*N/A*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Table 1, 2, 3 and page 8-9
		(*b*) Report category boundaries when continuous variables were categorized	See tables and methods
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	x
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
Discussion			
Key results	18	Summarise key results with reference to study objectives	10
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	4, 12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10-12
Generalisability	21	Discuss the generalisability (external validity) of the study results	10, 12
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

The association of longitudinal physical activity with current symptoms of insomnia, sleep duration and daytime sleepiness - A European population-based study

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Complete List of Authors:	Bjornsdottir, Erla; Reykjavik University Thorarinsdottir, Elin; Heilsugasla hofuoborgarsvaoisins; University of Iceland, Faculty of medicine Lindberg, Eva ; Uppsala University, Department of Medical Sciences: Respiratory, Allergy and Sleep Research Benediktsdottir, Bryndis; University of Iceland, Faculty of Medicine; Landspitali haskolasjukrahus, Department of Sleep Franklin, Karl; Umea Universitet, Department of Surgical and Perioperative Sciences Jarvis, Debbie; Imperial College London School of Public Health, Population Health and Occupational Disease, National Heart and Lung Institute; Imperial College London, MRC-PHE Centre for Environment and Health Demoly, Pascal ; University Hospital of Montpellier, France and Sorbonne Universités, University of Montpellier - Inserm UMR UA11 Perret, Jennifer; The University of Melbourne Melbourne Medical School Garcia Aymerich, Judith; ISGlobal, Centre for Research in Environmental Epidemiology (CREAL); Universitat Pompeu Fabra Dorado-Arenas, Sandra; Hospital Galdakao-Usansolo, Pulmonology Department Heinrich, Joachim; Ludwig Maximilians University Munich, Institute and Clinic for Occupational, Social and Environmental Medicine; The University of Melbourne Melbourne Medical School, Allergy and Lung Health Unit, Melbourne School of Population and Global Health Torén, Kjell; Goteborgs universitet Institutionen for medicin, Occupational and Environmental Medicine Garcia Larsen, Vanessa; Johns Hopkins University Bloomberg School of Public Health, 17Program in Human Nutrition, Department of International Health Jögi, Rain; Tartu University Hospital, The Lung Clinic Gislason, Thorarinn; University of Iceland, Faculty of Medicine; Landspitali haskolasjukrahus, Department of Sleep Janson, Christer; Uppsala University, Department of Medical Sciences: Respiratory, Allergy and Sleep Research
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Global health

Keywords:	SLEEP MEDICINE, EPIDEMIOLOGY, PRIMARY CARE, PUBLIC HEALTH, SPORTS MEDICINE

The association of longitudinal physical activity with current symptoms of insomnia, sleep duration and daytime sleepiness - A European population-based study

Erla Bjornsdottir[1*], Elin Helga Thorarinsdottir [2,3*], Eva Lindberg[4], Bryndis Benediktsdottir[3,5] , Karl A Franklin[6], Deborah L Jarvis[7,8], Pascal Demoly[9], Jennifer Perret[10], Judith Garcia-Aymerich[11,12], Sandra Dorado-Arenas[13], Joachim Heinrich[14,15], Kjell Toren[16], Vanessa Garcia Larsen[17], Rain Jogi[18] Thorarinn Gislason[3,5**]. Christer Janson[4**]

*Co-first authors, ** Co-senior author

Affiliations:
[1] University of Reykjavik, Iceland
[2] Primary Health Care of the Capital Area, Reykjavik, Iceland
[3] Faculty of Medicine, University of Iceland, Reykjavik, Iceland
[4] Department of Medical Sciences: Respiratory, Allergy and Sleep Research, Uppsala University, Uppsala, Sweden
[5] Department of Sleep, Landspitali - The National University Hospital of Iceland, Reykjavik, Iceland.
[6] Department of Surgical and Perioperative Sciences, Surgery, Umeå Univeristy, Umeå,Sweden
[7] Population Health and Occupational Disease, National Heart and Lung Institute, Imperial College London, London, UK
[8] MRC-PHE Centre for Environment and Health, Imperial College London, London, UK
[9] University Hospital of Montpellier, Montpellier, France and IDESP, University of Montpellier - Inserm UMR UA11
[10] University of Melbourne, Melbourne, Victoria, Australia.
[11] ISGlobal, Centre for Research in Environmental Epidemiology (CREAL), Barcelona, Spain
[12] Universitat Pompeu Fabra (UPF), Barcelona, Spain
[13] Pulmonology Department, Galdakao-Usansolo Hospital, OSI Barrualde-Galdakao (Osakidetza), Biscay, Spain
[14] Institute and Clinic for Occupational, Social and Environmental Medicine, University Hospital, LMU Munich, Comprehensive Pneumology Center (CPC-M) Munich, German Center for Lung Research (DZL)
[15] Allergy and Lung Health Unit, Melbourne School of Population and Global Health, The University of Melbourne, Melbourne, Australia
[16] Department of Occupational and Environmental Medicine, Institute of Medicine, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden
[17] Program in Human Nutrition, Department of International Health, The Johns Hopkins Bloomberg School of Public Health, Baltimore, USA.
[18] The Lung Clinic, Tartu University Hospital, Tartu, Estonia.

Correspondant author:
Erla Bjornsdottir
erlabjo@gmail.com
00354-8608009

Abstract:

Objectives: To explore the relationship of physical activity during the past 10 years with insomnia, daytime sleepiness and estimated short or long sleep duration among adults aged 39–67 years.

Design: Population-based, multi-centre cohort study.

Setting: 21 centres in 9 European countries.

Methods: Included were 4339 participants in the third follow-up of the European Community Respiratory Health Survey (ECRHS III) who answered questions on physical activity at baseline (ECRHS II) and questions on physical activity, insomnia symptoms, sleep duration and daytime sleepiness at follow up (ECRHS III). Physical activity was assessed both in ECRHS III and 10 years before. Participants reported that they exercised with a frequency of at least two or more times a week for one hour a week or more were classified as being physically active. Change in activity status was categorised into four groups: persistently non-active, became inactive, became active and persistently active.

Main outcome measures: Insomnia, sleep time and daytime sleepiness in relation to physical activity.

Results: Altogether, 37% of participants were persistently non-active, 25% were persistently active, 20% became inactive and 18% became active from baseline to follow up. Participants that were persistently active were less likely to report difficulties initiating sleep (OR 0.60 (95% CI 0.45-0.78)), short sleep duration of ≤6 h/night (OR 0.71 (95% CI 0.59-0.85) and long sleep of (≥9 h/night (OR 0.53 (95% CI 0.33-0.84)) than persistently non active subjects after adjusting for age, sex, BMI, smoking history, and study centre. Daytime sleepiness and difficulties maintaining sleep were not related to physical activity.

Conclusion: Physically active people have a lower risk of some insomnia symptoms and extreme sleep duration, both long and short.

Strengths and limitations of this study:

- The longitudinal study design, with the exposure (physical activity) measured 10 years before the outcome (sleep outcomes) allows testing the directionality of the association.

- Data was collected using standardized and validated procedures and instruments, increasing internal validity.

- Data was obtained from 9 European countries, increasing external validity of our findings.

- One limitation of our study is that sleep variables are only available at the follow-up, precluding testing their role on baseline physical activity.

- Insomnia symptoms, sleep length and daytime sleepiness were obtained from questionnaire and no sleep disorder diagnoses from medical providers or objective assessments were available.

Introduction

Disturbed sleep is common in the general population and impacts health and quality of life.(1-3) Chronic sleep disturbances are associated with cardiovascular disease, metabolic dysfunction, psychiatric disorders, and increased mortality.(4-6)

Physical activity and sleep: Regular exercise is associated with better health and several studies suggest that physical activity (PA) is beneficial on sleep and may improve symptoms of chronic insomnia.(7-10) It is, however, unclear how large these benefits are and which factors moderate these benefits.(11) The positive association between PA and sleep might be subject to multiple moderating factors such as gender, age, BMI, fitness level, general health and the characteristics of the exercise. Therefore, sleep and PA probably influence each other through complex, reciprocal interactions including multiple physiological and psychological pathways.(7)

Physical activity and daytime sleepiness: There is evidence that more PA is associated with less daytime sleepiness.(12-17) Cross-sectional studies have shown that low PA is associated with increased likelihood of excessive daytime sleepiness (EDS)(14-16) and that subjects participating in exercise are less likely to have EDS.(12, 17) In older adults, increasing PA by doing home exercises has been shown to improve EDS and reduce the prevalence of insomnia symptoms(13) and another study showed that increasing PA protected women from future insomnia.(18) Other studies have contradictory findings. In an epidemiological study of 4.405 Koreans, daytime sleepiness was more common among those in the top quartile of PA compared to those in the lowest quartile group.(19) Among patients with obstructive sleep apnoea increased PA was associated with lower disease severity and 28% decrease in EDS.(20) The daily association between PA and sleep duration was described in 2021 based on a systemic review and meta-analysis on 33 peer-reviewed papers showing that the night following an increased PA there was a lower total sleep time.(21)

Limitations of previous studies: There is a lack of epidemiological data from long-term follow-up of large cohorts studying the association of PA to sleep length, daytime sleepiness, and insomnia symptoms. Previous research on physical activity and sleep-related outcomes has several important limitations. Most studies are cross-sectional or with a short follow-up, preventing to elucidate if increased physical activity improves sleeping outcomes or reduced physical activity is a consequence of sleep problems. Finally, the effect of physical activity on sleep length, daytime sleepiness, and insomnia symptoms has not been studied simultaneously.

Aims of the current study: Therefore, the aim of the present study was to assess the interrelationship between physical activity based on frequency, duration and intensity and symptoms of insomnia, self-reported sleep duration and daytime sleepiness among middle-aged subjects from 21 centres in 9 countries at two time periods 10 years apart, giving important longitudinal follow up data.

Material and methods

Subjects:

We studied participants in the second and third follow-up of the European Community Respiratory Health Survey (ECRHS II and III, www.ecrhs.org), an international, population-based, multicentre cohort study of asthma and allergy, which was first performed in 1990. Detailed descriptions of the methods for ECRHS I and ECRHS II have been published elsewhere.(22, 23) Briefly, participating centres first randomly selected samples of 20 to 44-year-old subjects in order to follow them for the asthma, allergy and lung diseases (See: www.ecrhs.org). Participants completed a short postal questionnaire about asthma and asthma-like symptoms and from those who responded, a random sample was selected to undergo a more detailed clinical examination. In ECRHS II, subjects who had participated in the clinical phase of ECRHS I (performed between 1991 – 1994) were invited to participate in follow-up. The clinical phase of ECRHS II was performed between 1998 to 2002. ECRHS III is the second follow-up and was performed from February 2011 to January 2014.(22-24) The present study is based on data from ECRHS II and III (see figure 1 for flowchart). Ethical approval for the study from local research ethics committees and written consent from participants were obtained.

Health, habits, and measurements

Subjects answered the core ECRHS questionnaires which included questions on lifestyle, respiratory symptoms, smoking history, and general health. Current smokers were defined as those who smoked tobacco regularly during the last month. Former smokers were defined as smokers who denied having smoked regularly for a month prior to the examination. Those who reported no regular smoking at or prior to the examination were defined as never smokers. Height and weight were measured, and body mass index (BMI) was calculated.(24)

Assessment of physical activity

Physical activity was assessed in ECRHS II and III using replies from questionnaire in ECRHS II and III. The assessment of PA in ECRHS has previously been described in details and how both frequency and duration of PA was used to divide the population into categories.(22) In brief, participants were asked how often and for how many hours per week they usually exercised so that they got out of breath or became sweaty. Participants who exercised two or more times a week during at least 1 hour a week were classified physically active. Change in activity status from baseline to follow up was categorised into four PA groups: persistently non-active (non-active at both baseline and follow up), became inactive (active at baseline and non-active at follow up), became active (non-active at baseline and active at follow up) and persistently active (active at both baseline and follow up).

Sleep questionnaires and measurements

Sleep-related symptoms were assessed by using the Basic Nordic Sleep Questionnaire(25), where participants were asked about frequency of insomnia symptoms. Answers were on a scale of 1 – 5: (1) never or very seldom, (2) less than once a week, (3) once to twice a week, (4) three to five times a week, (5) every day or almost every day of the week. Insomnia symptoms were defined using answers to three questions from the Basic Nordic Sleep Questionnaire "I have difficulties falling asleep at night" (difficulties initiating sleep), "I wake up often during the night" (difficulties maintaining sleep) and "I wake up early in the morning and can't fall back asleep" (early morning awakenings). Those who reported those symptoms of insomnia ≥3 times a week (scores 4 and 5) were considered to have the corresponding insomnia subtype. Daytime sleepiness was evaluated using the Epworth Sleepiness Scale, a brief questionnaire that measures daytime sleepiness based on the likelihood of falling asleep in eight different situations.(26) Participants with Epworth sleepiness scale score >10 were considered to have EDS. Participants answered the question: how much sleep do you estimate that you get on average each night? They were classified as short sleepers (≤6 hours/night), normal sleepers (6–9 hours/night) and long sleepers (≥9 hours/night) according to their answers.

Patient and public involvement

The study´s design did not involve patients or the general public. However, all participating patients were informed about the research objectives, and their informed consent was obtained. The survey was completed by participants voluntarily and no input from patients was sought in interpreting or writing up the results. The results of the research will not be disseminated to the patients.

Statistical analysis

Data are presented as number and percentage or mean ±SD, depending on distribution. For bivariate analysis, the χ^2 test and one-way analysis of variance were used for nominal and continuous variables. Logistic regression was used for multivariable analyses to estimate the association between physical activity and sleep related outcomes. The model was adjusted for potential confounders including age, sex, BMI, smoking history and study center. In the analysis, all variables, including study center (n=21), were treated as fixed effects. STATA V.16 was used for all statistical analyses.

Results

Participants and level of physical activity

From a total of 5.850 participants in ECRHS II, we excluded those with missing data and included a total of 4.339 participants (48% men), see Figure 1. From baseline to 10 years later, 36.9% of participants were persistently non-active, 17.9% became physically active at follow-up, 20.3% of participants became inactive 24.9% were persistently active (Table 1). There were geographical differences in the level of physical activity between the ECRHS countries (Figure 2). Participants in Norway were most likely to be persistently active, while participants in Spain, followed by Estonia, were most likely to be persistently non-active (Figure 2).

General characteristics and health

Persistently active participants were more often men, they were younger, and they had slightly lower BMI (Table 1). They were also less likely to be current smokers and more likely to be currently working (Table 1).

Insomnia symptoms

In unadjusted analysis, there was a significant difference in reporting difficulties initiating sleep, early morning awakenings and any insomnia symptom where those persistently active were least likely to report these symptoms. Also, persistently active subjects were the least likely to report two and three insomnia symptoms (Table 2). After adjusting for age, sex, BMI, smoking history and study centre, this negative association remained for difficulties initiating sleep (OR 0.58 (0.42-0.77)), any insomnia symptom (OR 0.78 (0.65-0.94) and reporting two (OR 0.60 (0.43-0.82) and three (OR 0.63 (0.41-0.98) insomnia symptoms (Table 3). Additionally, in adjusted analysis, persistently active subjects were significantly less likely to report difficulties initiating sleep (OR 0.80 (0.66-0.97) (Table 3). There were also independent associations between insomnia symptoms and age, female gender and BMI (Table 4).

Sleep duration and daytime sleepiness

In unadjusted analysis, there was a significant difference in short and long sleep duration between levels of activity. Those who were persistently active were most likely to be normal sleepers and the persistently non-active were least likely (70.9% vs. 59.2% respectively) (Table 2). After adjusting for age, sex, BMI, smoking history and study centre, these results remained significant for persistently active subjects. They were significantly more likely to be normal sleepers (OR 1.55 (1.29-1.87)) and significantly less likely to be short sleepers (OR 0.71 (0.58-0.85)) or long sleepers (OR 0.48 (0.28-0.80)) (Table 3). Additionally, those who became active were more likely to be normal sleepers than those persistently non-active (OR 1.21 (1.00-1.47) (Table 3).

However, there was not a significant association between the mean Epworth sleepiness scale score or percentage with Epworth sleepiness scale score >10 and level of physical activity (Tables 2 and 3). Daytime sleepiness was also independently associated with smoking (Table 4).

Discussion

The main results of this study were that participants who reported being physically active at the start and end of a 10 year follow up period were less likely to report insomnia symptoms at the follow-up. We also found that subjects that are persistently active are more likely to sleep the recommended 6-9 hours. This association remained statistically significant after adjusting for sex, age, smoking history, and BMI. We also saw that persistently active participants were more often men, they were younger, and they had slightly lower BMI and were less likely to be current smokers and more likely to be currently working.

Our results are in line with previous studies that have shown a beneficial effect of physical activity on symptoms of insomnia (9, 10) but the current study additionally shows the importance of consistency in exercise over time because the association was lost in initially active subjects who became inactive. A recent meta- analysis examining the effects of acute and regular exercise on a range of sleep variables showed that acute exercise (less than one week of exercise) has a small beneficial effect on many objective measures of sleep such as total sleep time, symptoms of insomnia and sleep quality.(7) Furthermore, this meta-analysis found greater benefits for regular exercise on both subjective and objective sleep parameters over time. Regular exercise had small beneficial effects on total sleep time and sleep efficiency, small-to-medium beneficial effects on sleep onset latency, and moderate beneficial effects on sleep quality.(7)

There are two recent systematic reviews and meta-analysis on the effects of PA on sleep(7) and insomnia(9) both substantially reviewing the same randomized controlled studies. Banno *et al*. included nine studies with a total of 557 participants.(7) The majority of participants exercised 3 times or less per week and follow-up was 4 months or shorter in all studies except one. Their conclusion was that exercise could improve sleep, but higher quality research was needed.(7) Five studies on insomnia and additionally six on insomnia symptoms showed shorter sleep latency and higher sleep efficacy, but the authors also acknowledged the small size of the literature and severe methodological limitations often based on selection bias.(9) Most previous studies are also cross-sectional which can also be considered a limitation.

Furthermore, a recent systematic review on physical activity and sleep showed that moderate exercise had more promising outcome on sleep quality than vigorous exercise. It is therefore important to further study the impact of the intensity of physical activity in the context of age and gender when exploring the beneficial impact on sleep.(27)

This study has a long follow up period (10 years) and indicates strongly that consistency in physically activity might be an important factor to optimize sleep duration and reduce symptoms of insomnia. Most other studies have had a much shorter follow up period(7) which makes it more difficult to assess consistency in activity over time.

Our results indicate that those who are consistent in physical activity are also less likely to be both short (<6h) and long sleepers (>9h). Those who are physically active in general are also more likely to engage in a healthier lifestyle (28) which also can have an effect on sleep. Lifestyle factors such as healthy diet and physical activity are probably a part of a phenotype that characterizes those individuals who are generally engaged in a healthy lifestyle. A recent review highlighted the importance of focusing on the combination of sleep, diet and exercise when exploring healthy longevity.(29)

The three groups reporting low physical activity in either ECRHS survey or at both time points are all reporting very similar prevalence of insomnia symptoms, extreme sleep length and daytime sleepiness. This is somewhat surprising, especially that those who are active at the follow-up but were not at baseline do have very similar symptom profile as those who were inactive at both surveys. Our study found a consistency in a behaviour like physical activity for more than a decade is strongly related to less insomnia and more “normal” sleep length. The important information concerning “the healthy phenotype” would be missed if the physical activity data were available only at baseline or at follow-up but not at both time points.

In a recent review based on 22 randomized controlled trials on the effects of regular exercise (lasting at least 2 months on a regular basis) on self-reported sleep quality, insomnia and daytime sleepiness, it was found that regular physical activity improved subjective sleep quality, insomnia severity, and daytime sleepiness as measured only with the Epworth sleepiness scale.(27) These results regarding insomnia symptoms are in line with our study but the results on daytime sleepiness differ from our results. The reason for this discrepancy could be due to different study populations since there were only two studies in this review that measured daytime sleepiness using the Epworth sleepiness scale, one study assessed this among the elderly, 60 years and older(13) and the other among overweight and obese men.(30) Another recent review of 32 randomized control trials on the effects of exercise on improving sleep disturbances showed that exercise is beneficial in improving sleep quality, symptoms of insomnia, restless legs, sleep apnoea and daytime sleepiness. However, exercise only had significant effects on sleepiness if it had lasted for more than 12 weeks while the exercise period did not matter in regards of the association to sleep quality and insomnia symptoms.(31)

Another recent study showed that high or increasing levels of physical activity could protect women from future insomnia.(18) Therefore, exercise seems to have a stronger association with sleep quality and insomnia than with sleepiness, which is in line with our results. However almost all previous studies, have the limitation that the definition of sleepiness is limited to the estimate the likelihood of falling asleep but not the general feeling of sleepiness, that we have shown is also an important part of sleepiness.(32, 33) Another recent review exploring the associations of exercise, sleep and cognitive function among older adults showed that physical activity is associated with improved cognitive function but the association of sleep and cognitive function seems to be U-shaped, as too much or too little sleep is negatively associated with cognitive function.(34) We did not explore cognitive function in the current study but It would be interesting for future studies to explore further how cognitive function is affected by the association of physical activity and sleep.

This study has several strengths such as the population-based nature, the longitudinal study design and the large sample collected in the same manner at many centres in 9 different countries. Another strength is the use of standardized and validated procedures and instruments. The long follow up period is also a strength since data on physical activity is collected ten years apart and subjects are categorized according to change in physical activity. This study is however not without limitations. It is not possible to know whether those who are active at both timepoints have been continuously physically active throughout the study period or only at these two timepoints. Furthermore, physical activity was only measured using a questionnaire. Another limitation of our study is that sleep variables are only available at the follow-up, and we only have information on insomnia symptoms but not the diagnosis of insomnia disorder. Sleep length and daytime sleepiness are also based on subjective data. Therefore, even though the measurement of physical activity is longitudinal, it may not be entirely appropriate to describe the associations between physical activity and sleep outcomes as longitudinal. Also, there are potential implications of residual confounders that can influence both physical activity and sleep which were not explored in the current study (e.g. mental health, musculoskeletal disorders/ chronic pain) which could influence the study findings.

In conclusion, physical activity over time is associated with lower prevalence of insomnia symptoms and with sleeping between 6-9 hours per night.

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Ethics approval statement: Ethical approval for the study from the local research ethics committees and written consent from participants were obtained at each site.

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Table 1. Characteristics and general health of the participants by the level of physical activity

	Persistently non-active	Became inactive	Became active	Persistently active	p-value
General characteristics					
N, %	1601 (36.9)	881 (20.3)	775 (17.9)	1082 (24.9)	
Men, %	44.3	49.0	46.8	53.7	**<0.001**
Age, years	55.0 ± 7.2	54.5 ± 7.1	53.4 ± 7.2	53.7 ± 7.2	**<0.001**
Body mass index, kg/m^2	27.6 ± 5.2	27.1 ± 4.9	27.1 ± 4.8	27.0 ± 4.4	**0.007**
Currently working, %	82.7	85.8	88.9	90.4	**<0.001**
Smoking history					
Never, %	42.4	43.4	44.3	47.6	**<0.001**
Former, %	34.4	39.8	37.5	40.0	
Current, %	23.2	16.9	18.2	12.4	

Table 2. Insomnia symptoms, sleep duration and daytime sleepiness by level of physical activity.

	Persistently non-active (n=1601)	**Became inactive** (n=881)	**Became active** (n=775)	**Persistently Active** (n=1082)	p-value
Insomnia symptoms					
Difficulties initiating sleep (%)	15.4	14.0	11.7	8.2	**<0.001**
Difficulties maintaining sleep (%)	31.9	32.1	33.0	28.5	0.128
Early morning awakenings (%)	18.2	18.3	15.0	13.2	**0.002**
Any insomnia symptom (%)	41.0	41.5	39.5	34.9	**0.006**
Numbers of insomnia symptoms					
None (%)	58.4	58.2	61.0	64.9	**0.001**
One (%)	23.2	25.2	24.0	23.8	
Two (%)	11.9	10.6	10.0	7.8	
Three (%)	6.6	6.1	5.1	3.6	
Sleep duration					
Sleep time (hours)	6.8 ± 1.1	6.8 ± 1.0	6.9 ± 1.0	6.9 ± 0.9	0.234
Sleep time, %					**<0.001**
Short sleepers (≤ 6 hours)	35.9	31.9	20.7	26.9	
Normal sleepers (6 – 9 hours)	59.2	64.6	66.9	70.9	
Long sleepers (≥ 9 hours)	4.9	3.5	3.4	2.2	
Daytime sleepiness					
Epworth sleepiness scale score	6.8 ± 4.1	7.2 ± 4.1	6.9 ± 4.1	6.9 ± 3.8	0.106
Epworth sleepiness scale score >10 (%)	17.2	19.4	17.7	15.6	0.176

Data are presented as mean ± standard deviation or % where indicated. Significant differences are in bold ($p<0.05$). *p-value from Pearson´s chi-square test (numerical variables) and one-way analysis of variance (continuous variables).

Table 3. Independent association between the level of physical activity and medical disorders, insomnia symptoms, daytime sleepiness and sleep duration expressed as adjusted* odds ratios (95% CI) with the persistently non-active group as reference. Bold text indicates statistical significance.

	Became inactive (n=881)	**Became active** (n=775)	**Persistently active** (n=1082)
Insomnia symptoms			
Difficulties initiating sleep	0.97 (0.75-1.25)	0.82 (0.62-1.08)	**0.58 (0.42-0.77)**
Difficulties maintaining sleep	0.96 (0.80-1.17)	1.04 (0.85-1.27)	**0.80 (0.66-0.97)**
Early morning awakenings	1.09 (0.87-1.38)	0.86 (0.63-1.03)	0.80 (0.63-1.03)
Any insomnia symptom	1.02 (0.85-1.22)	0.95 (0.78-1.14)	**0.78 (0.65-0.94)**
Numbers of insomnia symptoms			
One	1.07 (0.86-1.32)	0.99 (0.79-1.24)	0.91 (0.74-1.12)
Two	0.89 (0.66-1.20)	0.86 (0.63-1.17)	**0.60 (0.43-0.82)**
Three	1.09 (0.74-1.59)	0.94 (0.62-1.42)	**0.63 (0.41-0.98)**
Daytime sleepiness			
Epworth sleepiness scale score >10	1.17 (0.94-1.47)	1.00 (0.78-1.27)	0.87 (0.69-1.10)
Sleep duration			
Short sleepers (≤ 6 hours)	0.89 (0.73-10.7)	0.85 (0.69-1.03)	**0.71 (0.58-0.85)**
Normal sleepers (6-9 hours)	1.18 (0.98-1.42)	**1.21 (1.00-1.47)**	**1.55 (1.29-1.87)**
Long sleepers (≥ 9 hours)	0.74 (0.47-1.17)	0.84 (0.53-1.33)	**0.48 (0.28-0.80)**

*Adjusted for age, sex, BMI, smoking history and center. Significant differences are in bold.

Table 4. Associations between age, sex, BMI and smoking history and sleep related symptoms.

	Age	Sex	BMI	Smoking history
Insomnia symptoms				
Difficulties initiating sleep	**1.02 (1.01-1.03)**	**2.16 (1.77-2.64)**	**1.02 (1.01-1.05)**	**0.81 (0.66-0.99)**
Difficulties maintaining sleep	**1.04 (1.03-1.05)**	**1.80 (1.56-2.07)**	**1.01 (1.00-1.03)**	1.09 (0.95-1.26)
Early morning awakenings	**1.02 (1.01-1.03)**	**1.52 (1.28-1.80)**	1.01 (1.00-1.03)	1.02 (0.85-1.21)
Any insomnia symptom	**1.03 (1.02-1.04)**	**1.75 (1.53-1.99)**	**1.02 (1.01-1.03)**	1.07 (0.93-1.22)
Numbers of insomnia symptoms				
One	**1.03 (1.01-1.04)**	**1.47 (1.26-1.71)**	**1.02 (1.00-1.03)**	1.15 (0.98-1.34)
Two	**1.04 (1.02-1.06)**	**2.11 (1.69-2.64)**	**1.02 (1.00-1.05)**	1.01 (0.80-1.26)
Three	**1.04 (1.02-1.06)**	**2.62 (1.93-3.53)**	1.03 (0.99-1.06)	0.89 (0.66-1.20)
Daytime sleepiness				
Epworth sleepiness scale score >10	0.99 (0.98-1.00)	0.95 (0.81-1.12)	1.01 (0.99-1.03)	**1.28 (1.08-1.52)**
Sleep duration				
Short sleepers (≤ 6 hours)	1.01 (0.99-1.02)	0.88 (0.77-1.00)	**1.03 (1.02-1.05)**	**0.83 (0.72-0.96)**
Normal sleepers (6-9 hours)	**0.99 (0.98-0.99)**	1.08 (0.95-1.23)	**0.96 (0.95-0.98)**	**1.20 (1.05-1.38)**
Long sleepers (≥ 9 hours)	**1.03 (1.01-1.06)**	1.35 (0.96-1.89)	1.02 (0.99-1.06)	0.95 (0.67-1.34)

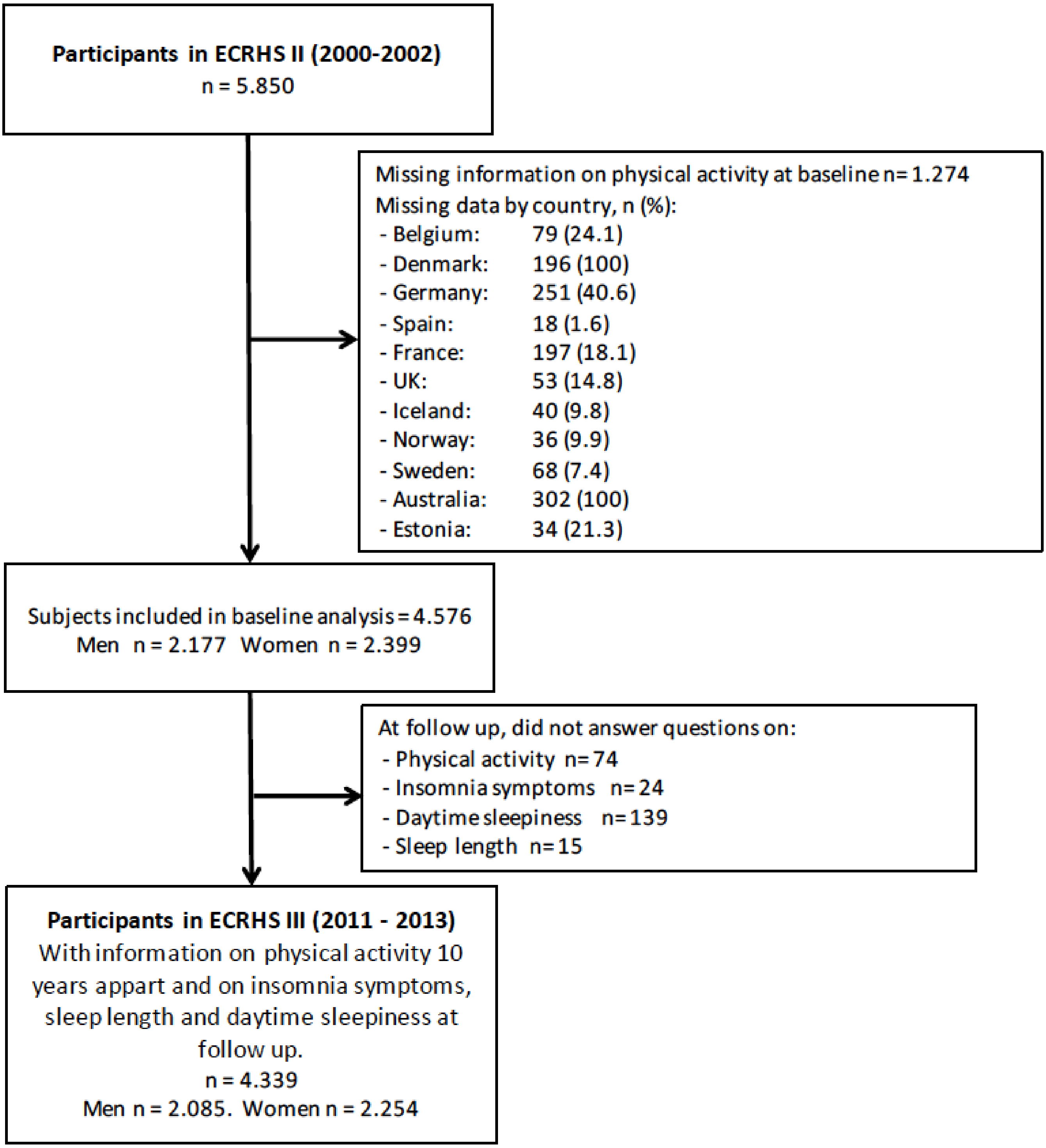
Figure legends:

Figure 1. Flow chart of the study population in the European community health survey (ECRSH)

Figure 2. Activity levels by country

Figure 3. Prevalence of any insomnia symptom, short sleep duration (≤6 hours per night), long sleep duration (≥9 hours per night) and daytime sleepiness (ESS>10) by country.

Figure 1. Flow chart of the study population in the European community health survey (ECRSH)



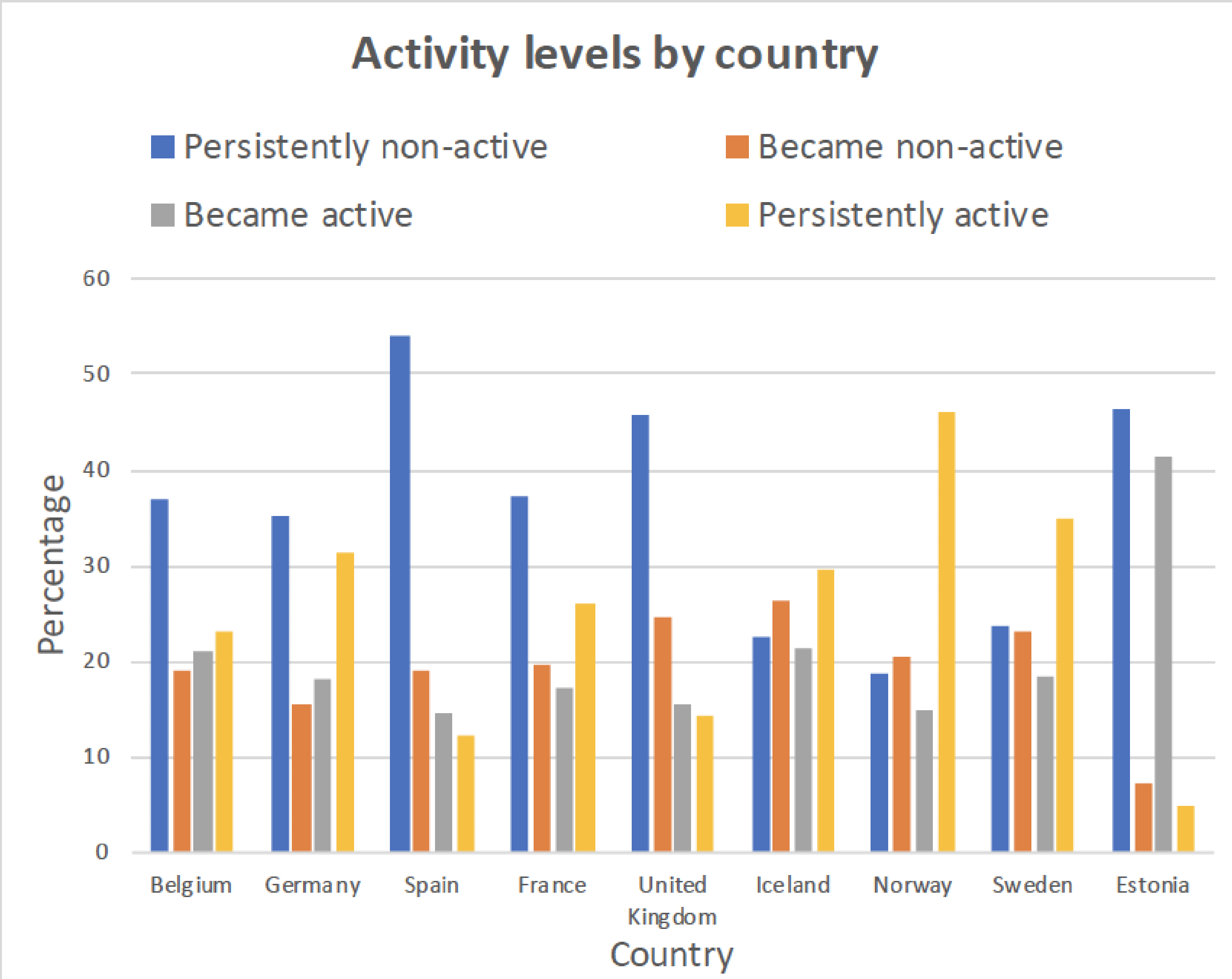


Figure 2. Activity levels by country

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	5-6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-8
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8
Bias	9	Describe any efforts to address potential sources of bias	4, 12
Study size	10	Explain how the study size was arrived at	8, fig 1
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7-8
		(*b*) Describe any methods used to examine subgroups and interactions	7-8
		(*c*) Explain how missing data were addressed	8, fig 1
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	8, fig 1

(*e*) Describe any sensitivity analyses

Continued on next page

Results

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8, fig 1
		(b) Give reasons for non-participation at each stage	8, fig 1
		(c) Consider use of a flow diagram	Fig 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8
		(b) Indicate number of participants with missing data for each variable of interest	Table 1
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	6
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	*8-9*
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	*N/A*
		Cross-sectional study—Report numbers of outcome events or summary measures	*N/A*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Table 1, 2, 3 and page 8-9
		(*b*) Report category boundaries when continuous variables were categorized	See tables and methods
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	x
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A

Discussion

Key results	18	Summarise key results with reference to study objectives	10
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	4, 12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10-12
Generalisability	21	Discuss the generalisability (external validity) of the study results	10, 12

Other information

Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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The association between physical activity over a 10-year period and current insomnia symptoms, sleep duration and daytime sleepiness – A European population-based study

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The association between physical activity over a 10-year period and current insomnia symptoms, sleep duration and daytime sleepiness – A European population-based study

Erla Bjornsdottir[1*], Elin Helga Thorarinsdottir [2,3*], Eva Lindberg[4], Bryndis Benediktsdottir[3,5] , Karl A Franklin[6], Deborah L Jarvis[7,8], Pascal Demoly[9,] Jennifer Perret[10], Judith Garcia-Aymerich[11,12], Sandra Dorado-Arenas[13], Joachim Heinrich[14,15], Kjell Toren[16], Vanessa Garcia Larsen[17], Rain Jogi[18] Thorarinn Gislason[3,5**.] Christer Janson[4**]

*Co-first authors, ** Co-senior author

Affiliations:
[1] University of Reykjavik, Iceland
[2] Primary Health Care of the Capital Area, Reykjavik, Iceland
[3] Faculty of Medicine, University of Iceland, Reykjavik, Iceland
[4] Department of Medical Sciences: Respiratory, Allergy and Sleep Research, Uppsala University, Uppsala, Sweden
[5] Department of Sleep, Landspitali - The National University Hospital of Iceland, Reykjavik, Iceland.
[6] Department of Surgical and Perioperative Sciences, Surgery, Umeå Univeristy, Umeå,Sweden
[7] Population Health and Occupational Disease, National Heart and Lung Institute, Imperial College London, London, UK
[8] MRC-PHE Centre for Environment and Health, Imperial College London, London, UK
[9] University Hospital of Montpellier, Montpellier, France and IDESP, University of Montpellier - Inserm UMR UA11
[10] University of Melbourne, Melbourne, Victoria, Australia.
[11]ISGlobal, Centre for Research in Environmental Epidemiology (CREAL), Barcelona, Spain
[12] Universitat Pompeu Fabra (UPF), Barcelona, Spain
[13] Pulmonology Department, Galdakao University Hospital, Osakidetza, Biocruces Bizkaia Health Research Insitute, Biscay, Spain
[14] Institute and Clinic for Occupational, Social and Environmental Medicine, University Hospital, LMU Munich, Comprehensive Pneumology Center (CPC-M) Munich, German Center for Lung Research (DZL)
[15] Allergy and Lung Health Unit, Melbourne School of Population and Global Health, The University of Melbourne, Melbourne, Australia
[16] Department of Occupational and Environmental Medicine, Institute of Medicine, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden
[17]Program in Human Nutrition, Department of International Health, The Johns Hopkins Bloomberg School of Public Health, Baltimore, USA.
[18]The Lung Clinic, Tartu University Hospital, Tartu, Estonia.

Corresponding author:
Erla Bjornsdottir
erlabjo@gmail.com
00354-8608009

Abstract:

Objectives: To explore the relationship between physical activity over a 10-year period and current symptoms of insomnia, daytime sleepiness and estimated sleep duration in adults aged 39–67.

Design: Population-based, multi-centre cohort study.

Setting: 21 centres in 9 European countries.

Methods: Included were 4,339 participants in the third follow-up to the European Community Respiratory Health Survey (ECRHS III), who answered questions on physical activity at baseline (ECRHS II) and questions on physical activity, insomnia symptoms, sleep duration and daytime sleepiness at 10-years follow up (ECRHS III). Participants who reported that they exercised with a frequency of at least two or more times a week, for one hour a week or more, were classified as being physically active. Changes in activity status were categorised into four groups: persistently non-active; became inactive; became active; and persistently active.

Main outcome measures: Insomnia, sleep time and daytime sleepiness in relation to physical activity.

Results: Altogether, 37% of participants were persistently non-active, 25% were persistently active, 20% became inactive and 18% became active from baseline to follow up. Participants who were persistently active were less likely to report difficulties initiating sleep (OR 0.60 (95% CI 0.45-0.78)), a short sleep duration of ≤6 h/night (OR 0.71 (95% CI 0.59-0.85)) and a long sleep of ≥9 h/night (OR 0.53 (95% CI 0.33-0.84) than persistently non-active subjects after adjusting for age, sex, BMI, smoking history and study centre. Daytime sleepiness and difficulties maintaining sleep were not related to physical activity status.

Conclusion: Physically active people have a lower risk of some insomnia symptoms and extreme sleep durations, both long and short.

Strengths and limitations of this study:

- The longitudinal study design, in which the exposure (physical activity) is measured 10 years prior to the sleep outcomes, enables an investigation into whether the consistency of physical activity over time has an impact on current symptoms of insomnia, sleep duration and daytime sleepiness.
- Data was collected using standardized and validated procedures and instruments, increasing its internal validity.
- Data was obtained from nine European countries, increasing the external validity of our findings.
- One limitation of our study is that sleep variables are only available at the follow up, which precluded testing their effect on baseline physical activity.
- Insomnia symptoms, sleep durations and daytime sleepiness data were obtained by questionnaire and no sleep disorder diagnoses from medical providers or objective assessments were available.

Introduction

Disturbed sleep is common in the general population and impacts health and quality of life.(1-3) Chronic sleep disturbances are associated with cardiovascular disease, metabolic dysfunction, psychiatric disorders, and increased mortality.(4-6)

Physical activity and sleep: Regular exercise is associated with better health and several studies suggest that physical activity (PA) is beneficial to sleep and may improve symptoms of chronic insomnia.(7-10) It is, however, unclear how significant these benefits are and which factors may have a moderating effect upon them.(11) The positive association between PA and sleep may be subject to multiple moderating factors such as gender, age, BMI, fitness level, general health and the characteristics of the type of exercise in question. Therefore, sleep and PA probably influence each other through complex, reciprocal interactions including multiple physiological and psychological pathways.(7)

Physical activity and daytime sleepiness: There is evidence that more PA is associated with less daytime sleepiness.(12-17) Cross-sectional studies have shown that low PA is associated with an increased likelihood of excessive daytime sleepiness (EDS)(14-16) and that subjects participating in exercise are less likely to have EDS.(12, 17) In older adults, increasing PA by doing home exercises has been shown to improve EDS and reduce the prevalence of insomnia symptoms(13), while another study showed that increasing PA protected women from future insomnia.(18) Other studies have contradictory findings. In an epidemiological study of 4,405 Koreans, daytime sleepiness was more common among those in the top quartile of PA compared to those in the lowest quartile group.(19) Among patients with obstructive sleep apnoea, increased PA was associated with a lower severity of disease and a 28% decrease in EDS.(20) The daily association between PA and sleep duration was described in 2021, based on a systematic review and meta-analysis of 33 peer-reviewed papers, which showed that, on the night following increased PA, there was a lower total sleep time.(21)

Limitations of previous studies: There is a lack of epidemiological data from long-term follow up studies of large cohorts exploring the association of PA with sleep length, daytime sleepiness and insomnia symptoms. Previous research on physical activity and sleep-related outcomes has several important limitations. Most studies are cross-sectional or have a short follow-up interval, preventing the possibility of elucidating whether increased physical activity improves sleeping outcomes or whether reduced physical activity is a consequence of sleep problems. Finally, the effects of physical activity on sleep length, daytime sleepiness, and insomnia symptoms have not been studied simultaneously.

Aims of the current study: Therefore, the aim of the present study was to assess the interrelationship between physical activity, based on frequency, duration and intensity, and symptoms of insomnia, self-reported sleep durations and daytime sleepiness among middle-aged subjects from 21 centres in nine countries at two moments in time, 10 years apart, providing important longitudinal follow-up data.

Material and methods

Subjects:

We studied participants from the second and third follow-up surveys of the European Community Respiratory Health Survey (ECRHS II and III, www.ecrhs.org), an international, population-based, multi-centre cohort study of asthma and allergic disease, which was first carried out in 1990. Detailed descriptions of the methods used for ECRHS I and ECRHS II have been published elsewhere.(22, 23) Briefly, participating centres randomly selected samples from subjects aged 20 to 44 in order to track them for asthma, allergy and lung disease (See: www.ecrhs.org). Participants completed a short postal questionnaire about asthma and asthma-like symptoms and, from those who responded, a random sample was selected to undergo a more detailed clinical examination. In ECRHS II, subjects who had participated in the clinical phase of ECRHS I (performed between 1991 and 1994) were invited to participate in the follow-up study. The clinical phase of ECRHS II was carried out between 1998 and 2002. ECRHS III is the second follow-up study and was carried out from February 2011 to January 2014.(22-24) The present study is based on data from ECRHS II and III (see figure 1 for flowchart). Ethical approval for the study from local research ethics committees, and written consent from participants, were obtained.

Health, habits and measurements

Subjects answered the core ECRHS questionnaires, which included questions on lifestyle, respiratory symptoms, smoking history and general health. ‘Current smokers’ were defined as those who smoked tobacco regularly during the last month. ‘Former smokers’ were defined as smokers who denied having smoked regularly in the month prior to the examination. Those who reported no regular smoking at the time of, or prior to, the examination, were defined as ‘never smokers’. The participants’ height and weight were measured and their body mass index (BMI) was calculated.(24)

Assessment of physical activity

Physical activity was assessed in ECRHS II and III using replies from questionnaires. The assessment of PA in ECRHS has previously been described in detail, including how both the frequency and duration of PA were used to divide the population into categories.(22) In brief, participants were asked how often and for how many hours per week they usually exercised to the point that they became out of breath or sweaty. Participants who exercised two or more times a week, for at least 1 hour a week, were classified as physically active. Changes in activity status from baseline to follow up were categorised into four PA groups: persistently non-active (non-active at both baseline and follow up), became inactive (active at baseline and non-active at follow up), became active (non-active at baseline and active at follow up) and persistently active (active at both baseline and follow up).

Sleep questionnaires and measurements

Sleep-related symptoms were assessed using the Basic Nordic Sleep Questionnaire(25), where participants were asked about the frequency of insomnia symptoms. Answers were provided on a scale of 1–5: (1) never or very seldom, (2) less than once a week, (3) once to twice a week, (4) three to five times a week, (5) every day or almost every day of the week. Insomnia symptoms were defined using answers to three questions from the Basic Nordic Sleep Questionnaire: “I have difficulties falling asleep at night” (difficulties initiating sleep), “I wake up often during the night” (difficulties maintaining sleep) and “I wake up early in the morning and can’t fall back asleep” (early morning awakenings). Those who reported these symptoms of insomnia ≥3 times a week (scores 4 and 5) were considered to have the corresponding insomnia subtype. Daytime sleepiness was evaluated using the Epworth Sleepiness Scale, a brief questionnaire that measures daytime sleepiness based on the likelihood of falling asleep in eight different situations.(26) Participants with an Epworth sleepiness scale score >10 were considered to have EDS.

Participants were asked the question: how much sleep do you estimate that you get on average each night? According to their answers, they were classified as: short sleepers (≤6 hours/night), normal sleepers (6–9 hours/night) or long sleepers (≥9 hours/night).

Patient and public involvement

The study's design did not involve patients or the general public. However, all participating patients were informed of the research objectives and their informed consent was obtained. The survey was completed by participants voluntarily and no input from patients was sought in interpreting or writing up the results. The results of the research will not be disseminated to the patients.

Statistical analysis

Data are presented as numbers and percentages or mean ±SD, depending on distribution. For bivariate analysis, the χ^2 test and one-way analysis of variance were used for nominal and continuous variables. Logistic regression was used for multivariable analyses to estimate the association between physical activity and sleep-related outcomes. The model was adjusted for potential confounders including age, sex, BMI, smoking history and study centre. In the analysis, all variables, including study centre (n=21), were treated as fixed effects. STATA V.16 was used for all statistical analyses.

Results

Participants and level of physical activity

From a total of 5,850 participants in ECRHS II, we excluded those with missing data and included a total of 4,339 participants (48% men), see Figure 1. Figure 2 shows the prevalence of insomnia symptoms, short and long sleep durations, and daytime sleepiness among subjects in the different countries included in the study. From baseline to 10 years later, 36.9% of participants were persistently non-active, 17.9% became physically active at follow up, 20.3% of participants became inactive, and 24.9% were persistently active (Table 1). There were geographical differences in the level of physical activity between the ECRHS countries (Figure 3). Participants in Norway were most likely to be persistently active, while participants in Spain, followed by Estonia, were most likely to be persistently non-active (Figure 3).

General characteristics and health

Persistently active participants were more often men, they were younger, and they had a slightly lower BMI (Table 1). They were also less likely to be current smokers and more likely to be currently working (Table 1).

Insomnia symptoms

In unadjusted analysis, there was a significant difference in reporting difficulties initiating sleep, early morning awakenings and any insomnia symptom where those persistently active were least likely to report these symptoms. Also, persistently active subjects were the least likely to report having two or three insomnia symptoms (Table 2). After adjusting for age, sex, BMI, smoking history and study centre, this negative association remained significant for difficulties initiating sleep (OR 0.58 (0.42-0.77)), any insomnia symptom (OR 0.78 (0.65-0.94) and reporting two (OR 0.60 (0.43-0.82) and three (OR 0.63 (0.41-0.98) insomnia symptoms (Table 3). Additionally, in adjusted analysis, persistently active subjects were significantly less likely to report difficulties initiating sleep (OR 0.80 (0.66-0.97) (Table 3). There were also independent associations between insomnia symptoms and age, female gender and BMI (Table 4).

Sleep duration and daytime sleepiness

In unadjusted analysis, there was a significant difference in short and long sleep durations between levels of activity. Those who were persistently active were most likely to be normal sleepers while the persistently non-active were least likely to be in that category (70.9% vs. 59.2% respectively) (Table 2). After adjusting for age, sex, BMI, smoking history and study centre, these results remained significant for persistently active subjects. They were significantly more likely to be normal sleepers (OR 1.55 (1.29-1.87)) and significantly less likely to be short sleepers (OR 0.71 (0.58-0.85)) or long sleepers (OR 0.48 (0.28-0.80)) (Table 3). Additionally, those who became active were more likely to be normal sleepers than those who were persistently non-active (OR 1.21 (1.00-1.47) (Table 3).

However, there was not a significant association between the mean Epworth sleepiness scale score or percentage with an Epworth sleepiness scale score >10 and level of physical activity (Tables 2 and 3). Daytime sleepiness was also independently associated with smoking (Table 4).

Discussion

The main results of this study were that participants who reported being physically active at the start and end of a 10-year follow-up period were less likely to report insomnia symptoms at the follow up. We also found that subjects who are persistently active are more likely to sleep the recommended 6-9 hours. This association remained statistically significant after adjusting for sex, age, smoking history and BMI. We also found that persistently active participants were more often men, were younger, had a slightly lower BMI and were less likely to be current smokers and more likely to be currently working.

Our results are in line with previous studies that have shown the beneficial effect of physical activity on symptoms of insomnia (9, 10), but the current study additionally shows the importance of consistency in exercising over time, because the association was lost for initially active subjects who became inactive. A recent meta-analysis examining the effects of acute and regular exercise on a range of sleep variables showed that acute exercise (less than one week of exercise) has a small beneficial effect on many objective measures of sleep, such as total sleep time, insomnia symptoms and sleep quality.(7) Furthermore, this meta-analysis found greater benefits from regular exercise for both subjective and objective sleep parameters over time. Regular exercise had small beneficial effects on total sleep time and sleep efficiency, small-to-medium beneficial effects on sleep onset latency, and moderate beneficial effects on sleep quality.(7)

There are two recent systematic reviews and meta-analyses on the effects of PA on sleep(7) and insomnia(9), both substantially reviewing the same randomized controlled studies. Banno *et al*. included nine studies with a total of 557 participants.(7) The majority of participants exercised 3 times or less per week and the follow up interval was 4 months or shorter in all the studies except one. Their conclusion was that exercise could improve sleep, but that higher quality research was needed.(7) Five studies on insomnia, and, additionally, six on insomnia symptoms, showed shorter sleep latency and higher sleep efficacy, but the authors also acknowledged the small size of the literature and severe methodological limitations, often based on selection bias.(9) In addition, most previous studies are cross-sectional, which can also be considered a limitation.

Furthermore, a recent systematic review of physical activity and sleep showed that moderate exercise had a more promising outcome in terms of sleep quality than vigorous exercise. It is therefore important to study further the impact of the intensity of physical activity, in the context of age and gender, when exploring any beneficial impact on sleep.(27)

This study has a long follow-up period (10 years) and indicates strongly that consistency in physical activity might be an important factor in optimizing sleep duration and reducing the symptoms of insomnia. Most other studies have had a much shorter follow-up period(7), which makes it more difficult to assess the consistency of activity over time.

Our results indicate that those who maintain a consistent level of physical activity are also less likely to be both short (<6h) and long sleepers (>9h). Those who are physically active in general are also more likely to engage in a healthier lifestyle (28), which can likewise have an effect on sleep. Lifestyle factors, such as a healthy diet and being physically active, are probably part of a phenotype that characterizes those individuals who are generally engaged in a healthy lifestyle. A recent review highlighted the importance of focusing on the combination of sleep, diet and exercise when exploring healthy longevity.(29)

The three groups reporting low physical activity in either of the ECRHS surveys, or at both points in time, all report a very similar prevalence of insomnia symptoms, extreme sleep lengths and daytime sleepiness. This is somewhat surprising, especially given that those who were active in the follow-up survey but not at the baseline have a very similar symptom profile to those who were inactive in both surveys. Our study found that consistency in a behaviour such as physical activity for more than a decade is strongly related to a lower incidence of insomnia and a more “normal” sleep length. Important information concerning “the healthy phenotype” would be missed if the physical activity data were available only at baseline or at follow up but not at both time points.

In a recent review based on 22 randomized controlled trials concerning the effects of regular exercise (lasting at least two months on a regular basis) on self-reported sleep quality, insomnia and daytime sleepiness, it was found that regular physical activity improved subjective sleep quality, insomnia severity and daytime sleepiness as measured with the Epworth sleepiness scale.(30) These results regarding insomnia symptoms are in line with our study, but the results on daytime sleepiness differ from our results. The reason for this discrepancy could be due to different study populations, as there were only two studies in this review that measured daytime sleepiness using the Epworth sleepiness scale; one study assessed this among the elderly, 60 years and older(13), and the other among overweight and obese men.(31) Another recent review of 32 randomized control trials on the effects of exercise on improving sleep disturbances showed that exercise is beneficial in improving sleep quality, symptoms of insomnia, restless legs, sleep apnoea and daytime sleepiness. However, exercise only had significant effects on sleepiness if it had lasted for more than 12 weeks, while the exercise period did not matter in regards of the association to sleep quality and insomnia symptoms.(32)

Another recent study showed that high or increasing levels of physical activity could protect women from future insomnia.(18) Therefore, exercise seems to have a stronger association with sleep quality and insomnia than with sleepiness, which is in line with our results. However almost all previous studies, have the limitation that the definition of sleepiness is limited to the estimate the likelihood of falling asleep but not the general feeling of sleepiness, that we have shown is also an important part of sleepiness.(33, 34) Another recent review exploring the associations of exercise, sleep and cognitive function among older adults showed that physical activity is associated with improved cognitive function but the association of sleep and cognitive function seems to be U-shaped, as too much or too little sleep is negatively associated with cognitive function.(35) We did not explore cognitive function in the current study but It would be interesting for future studies to explore further how cognitive function is affected by the association of physical activity and sleep.

This study has several strengths such as the population-based nature, the longitudinal study design and the large sample collected in the same manner at many centres in 9 different countries. Another strength is the use of standardized and validated procedures and instruments. The long follow up period is also a strength since data on physical activity is collected ten years apart and subjects are categorized according to change in physical activity. This study is however not without limitations. It is not possible to know whether those who are active at both timepoints have been continuously physically active throughout the study period or only at these two timepoints. Furthermore, physical activity was only measured using a questionnaire. Another limitation of our study is that sleep variables are only available at the follow-up, and we only have information on insomnia symptoms but not the diagnosis of insomnia disorder. Sleep length and daytime sleepiness are also based on subjective data. Therefore, even though the measurement of physical activity is longitudinal, it may not be entirely appropriate to describe the associations between physical activity and sleep outcomes as longitudinal. Also, there are potential implications of residual confounders that can influence both physical activity and sleep which were not explored in the current study (e.g. mental health, musculoskeletal disorders/ chronic pain) which could influence the study findings.

In conclusion, physical activity over time is associated with lower prevalence of insomnia symptoms and with sleeping between 6-9 hours per night.

Contributors: EHT and EB are the co-first authors of the paper and they equally drafted, participated in manuscript preparation and were responsible for communications with other co-authors. TG and CJ participated in the design of the study, in the manuscript preparation and in review of the manuscript on several stages. EHT performed the statistical analysis with help from CJ. Eva Lindberg, Bryndis Benediktsdottir, Karl A Franklin, Deborah L Jarvis, Pascal Demoly, Jennifer Perret, Judith Garcia-Aymerich, Sandra Dorado-Arenas, Joachim Heinrich, Kjell Toren, Vanessa Garcia Larsen and Rain Jogi participated in data collection and/or in reviewing of the paper.

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Table 1. Characteristics and general health of the participants by the level of physical activity

	Persistently non-active	Became inactive	Became active	Persistently active	p-value
General characteristics					
N, %	1601 (36.9)	881 (20.3)	775 (17.9)	1082 (24.9)	
Men, %	44.3	49.0	46.8	53.7	**<0.001**
Age, years	55.0 ± 7.2	54.5 ± 7.1	53.4 ± 7.2	53.7 ± 7.2	**<0.001**
Body mass index, kg/m^2	27.6 ± 5.2	27.1 ± 4.9	27.1 ± 4.8	27.0 ± 4.4	**0.007**
Currently working, %	82.7	85.8	88.9	90.4	**<0.001**
Smoking history					
Never, %	42.4	43.4	44.3	47.6	**<0.001**
Former, %	34.4	39.8	37.5	40.0	
Current, %	23.2	16.9	18.2	12.4	

Table 2. Insomnia symptoms, sleep duration and daytime sleepiness by level of physical activity.

	Persistently non-active (n=1601)	**Became inactive** (n=881)	**Became active** (n=775)	**Persistently Active** (n=1082)	p-value
Insomnia symptoms					
Difficulties initiating sleep (%)	15.4	14.0	11.7	8.2	**<0.001**
Difficulties maintaining sleep (%)	31.9	32.1	33.0	28.5	0.128
Early morning awakenings (%)	18.2	18.3	15.0	13.2	**0.002**
Any insomnia symptom (%)	41.0	41.5	39.5	34.9	**0.006**
Numbers of insomnia symptoms					
None (%)	58.4	58.2	61.0	64.9	**0.001**
One (%)	23.2	25.2	24.0	23.8	
Two (%)	11.9	10.6	10.0	7.8	
Three (%)	6.6	6.1	5.1	3.6	
Sleep duration					
Sleep time (hours)	6.8 ± 1.1	6.8 ± 1.0	6.9 ± 1.0	6.9 ± 0.9	0.234
Sleep time, %					**<0.001**
Short sleepers (≤ 6 hours)	35.9	31.9	20.7	26.9	
Normal sleepers (6 – 9 hours)	59.2	64.6	66.9	70.9	
Long sleepers (≥ 9 hours)	4.9	3.5	3.4	2.2	
Daytime sleepiness					
Epworth sleepiness scale score	6.8 ± 4.1	7.2 ± 4.1	6.9 ± 4.1	6.9 ± 3.8	0.106
Epworth sleepiness scale score >10 (%)	17.2	19.4	17.7	15.6	0.176

Data are presented as mean ± standard deviation or % where indicated. Significant differences are in bold ($p<0.05$). *p-value from Pearson´s chi-square test (numerical variables) and one-way analysis of variance (continuous variables).

Table 3. Independent association between the level of physical activity and medical disorders, insomnia symptoms, daytime sleepiness and sleep duration expressed as adjusted* odds ratios (95% CI) with the persistently non-active group as reference. Bold text indicates statistical significance.

	Became inactive (n=881)	**Became active** (n=775)	**Persistently active** (n=1082)
Insomnia symptoms			
Difficulties initiating sleep	0.97 (0.75-1.25)	0.82 (0.62-1.08)	**0.58 (0.42-0.77)**
Difficulties maintaining sleep	0.96 (0.80-1.17)	1.04 (0.85-1.27)	**0.80 (0.66-0.97)**
Early morning awakenings	1.09 (0.87-1.38)	0.86 (0.63-1.03)	0.80 (0.63-1.03)
Any insomnia symptom	1.02 (0.85-1.22)	0.95 (0.78-1.14)	**0.78 (0.65-0.94)**
Numbers of insomnia symptoms			
One	1.07 (0.86-1.32)	0.99 (0.79-1.24)	0.91 (0.74-1.12)
Two	0.89 (0.66-1.20)	0.86 (0.63-1.17)	**0.60 (0.43-0.82)**
Three	1.09 (0.74-1.59)	0.94 (0.62-1.42)	**0.63 (0.41-0.98)**
Daytime sleepiness			
Epworth sleepiness scale score >10	1.17 (0.94-1.47)	1.00 (0.78-1.27)	0.87 (0.69-1.10)
Sleep duration			
Short sleepers (≤ 6 hours)	0.89 (0.73-10.7)	0.85 (0.69-1.03)	**0.71 (0.58-0.85)**
Normal sleepers (6-9 hours)	1.18 (0.98-1.42)	**1.21 (1.00-1.47)**	**1.55 (1.29-1.87)**
Long sleepers (≥ 9 hours)	0.74 (0.47-1.17)	0.84 (0.53-1.33)	**0.48 (0.28-0.80)**

*Adjusted for age, sex, BMI, smoking history and center. Significant differences are in bold.

Table 4. Associations between age, sex, BMI and smoking history and sleep related symptoms.

	Age	Sex	BMI	Smoking history
Insomnia symptoms				
Difficulties initiating sleep	**1.02 (1.01-1.03)**	**2.16 (1.77-2.64)**	**1.02 (1.01-1.05)**	**0.81 (0.66-0.99)**
Difficulties maintaining sleep	**1.04 (1.03-1.05)**	**1.80 (1.56-2.07)**	**1.01 (1.00-1.03)**	1.09 (0.95-1.26)
Early morning awakenings	**1.02 (1.01-1.03)**	**1.52 (1.28-1.80)**	1.01 (1.00-1.03)	1.02 (0.85-1.21)
Any insomnia symptom	**1.03 (1.02-1.04)**	**1.75 (1.53-1.99)**	**1.02 (1.01-1.03)**	1.07 (0.93-1.22)
Numbers of insomnia symptoms				
One	**1.03 (1.01-1.04)**	**1.47 (1.26-1.71)**	**1.02 (1.00-1.03)**	1.15 (0.98-1.34)
Two	**1.04 (1.02-1.06)**	**2.11 (1.69-2.64)**	**1.02 (1.00-1.05)**	1.01 (0.80-1.26)
Three	**1.04 (1.02-1.06)**	**2.62 (1.93-3.53)**	1.03 (0.99-1.06)	0.89 (0.66-1.20)
Daytime sleepiness				
Epworth sleepiness scale score >10	0.99 (0.98-1.00)	0.95 (0.81-1.12)	1.01 (0.99-1.03)	**1.28 (1.08-1.52)**
Sleep duration				
Short sleepers (≤ 6 hours)	1.01 (0.99-1.02)	0.88 (0.77-1.00)	**1.03 (1.02-1.05)**	**0.83 (0.72-0.96)**
Normal sleepers (6-9 hours)	**0.99 (0.98-0.99)**	1.08 (0.95-1.23)	**0.96 (0.95-0.98)**	**1.20 (1.05-1.38)**
Long sleepers (≥ 9 hours)	**1.03 (1.01-1.06)**	1.35 (0.96-1.89)	1.02 (0.99-1.06)	0.95 (0.67-1.34)

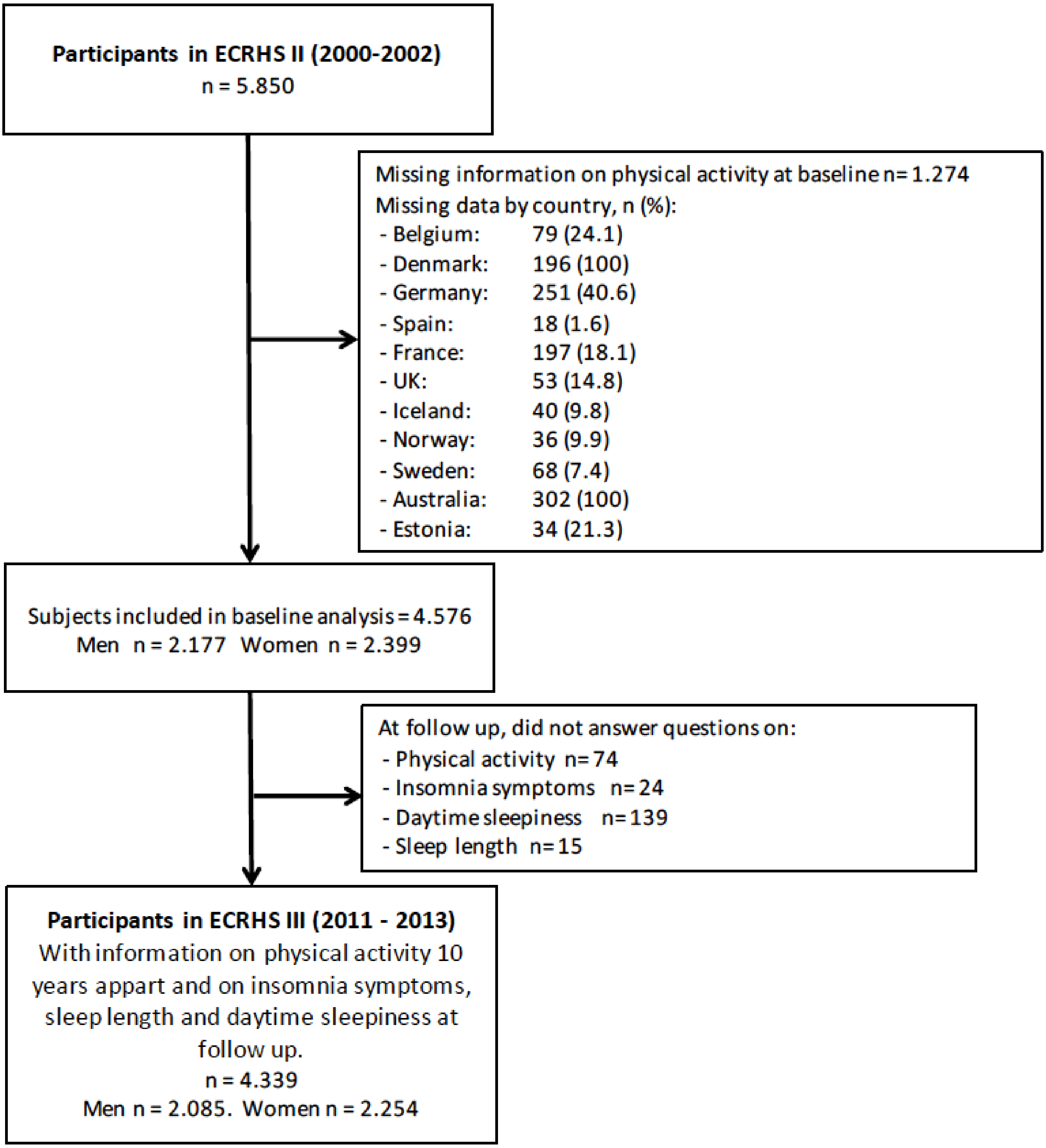
Figure legends:

Figure 1. Flow chart of the study population in the European community health survey (ECRSH)

Figure 2. Prevalence of any insomnia symptom, short sleep duration (≤6 hours per night), long sleep duration (≥9 hours per night) and daytime sleepiness (ESS>10) by country

Figure 3. Activity levels by country

Figure 1. Flow chart of the study population in the European community health survey (ECRSH)



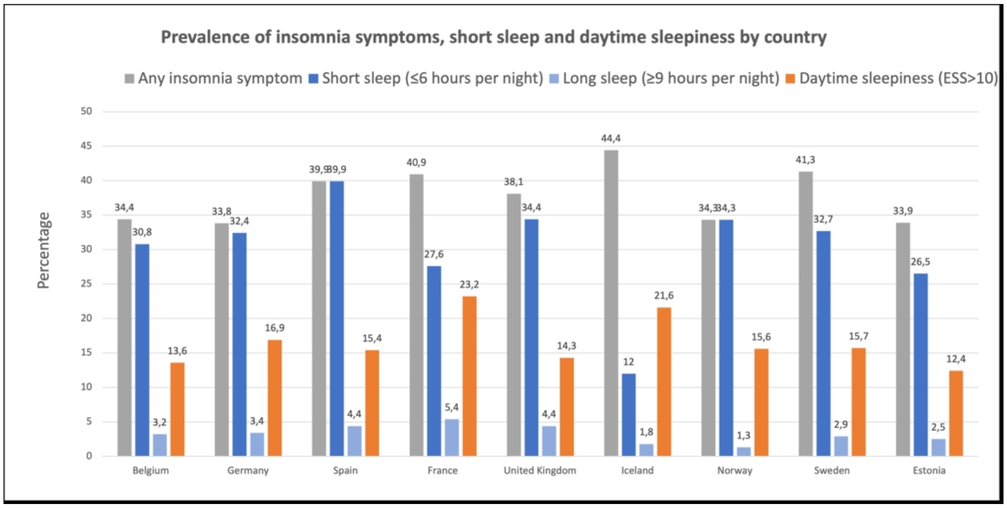


Figure 2. Prevalence of any insomnia symptom, short sleep duration (≤6 hours per night), long sleep duration (≥9 hours per night) and daytime sleepiness (ESS>10) by country

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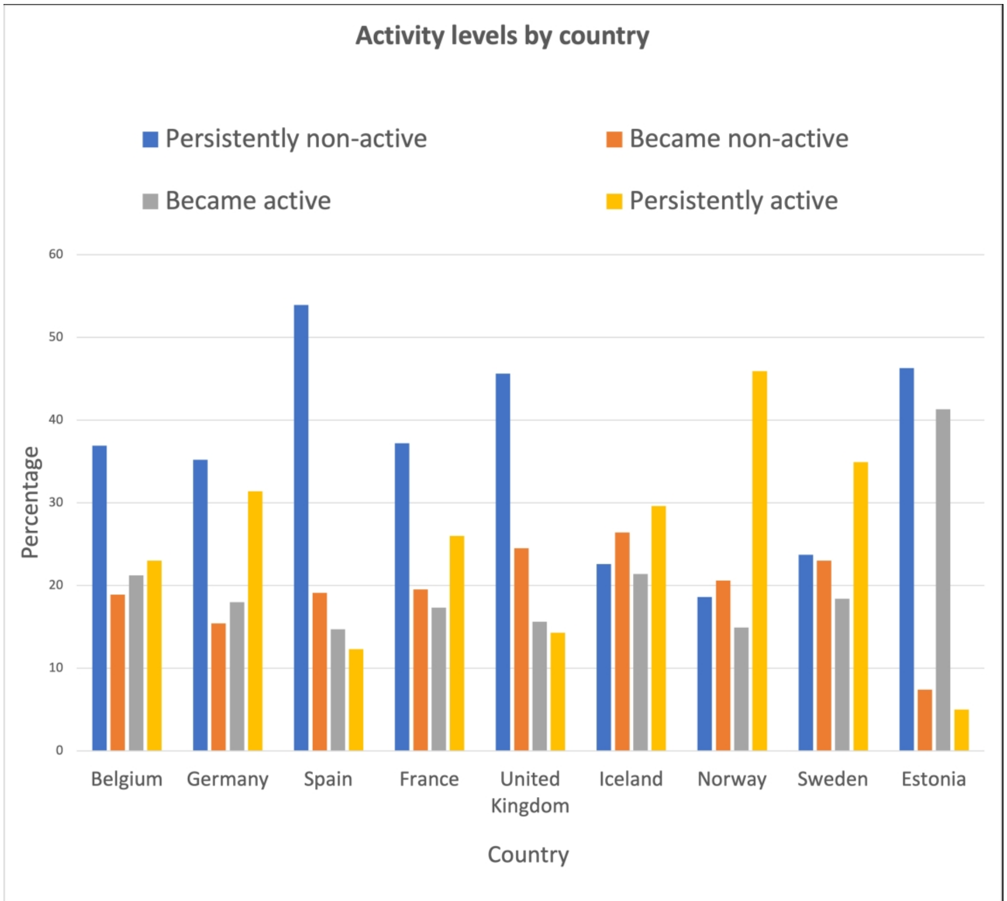

Figure 3. Activity levels by country

224x202mm (300 x 300 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	5-6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-8
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	6
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8
Bias	9	Describe any efforts to address potential sources of bias	4, 12
Study size	10	Explain how the study size was arrived at	8, fig 1
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7-8
		(*b*) Describe any methods used to examine subgroups and interactions	7-8
		(*c*) Explain how missing data were addressed	8, fig 1
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	8, fig 1

(*e*) Describe any sensitivity analyses

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8, fig 1
		(b) Give reasons for non-participation at each stage	8, fig 1
		(c) Consider use of a flow diagram	Fig 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8
		(b) Indicate number of participants with missing data for each variable of interest	Table 1
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	6
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	*8-9*
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	*N/A*
		Cross-sectional study—Report numbers of outcome events or summary measures	*N/A*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Table 1, 2, 3 and page 8-9
		(*b*) Report category boundaries when continuous variables were categorized	See tables and methods
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	x
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
Discussion			
Key results	18	Summarise key results with reference to study objectives	10
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	4, 12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10-12
Generalisability	21	Discuss the generalisability (external validity) of the study results	10, 12
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.