Sleep Health: Journal of the National Sleep Foundation 10 (2024) 171–181

Contents lists available at ScienceDirect

Sleep Health: Journal of the National Sleep Foundation

journal homepage: www.sleephealthjournal.org

Nonlinear associations between insomnia symptoms and circadian preferences in the general population: Symptom-specific and lifespan differences in men and women

Dina Sarsembayeva, MRes [a,*], Catharina A. Hartman, PhD [a], Raniere Dener Cardoso Melo, MRes [a], Marieke J. Schreuder, PhD [b]

[a] Interdisciplinary Centre Psychopathology and Emotion Regulation, University Center of Psychiatry, University Medical Center Groningen, University of Groningen, Groningen, the Netherlands
[b] Quantitative Psychology and Individual Differences, Department of Psychology and Education Sciences, KU Leuven, Leuven, Belgium

ARTICLE INFO

Article history:
Received 8 February 2023
Received in revised form 26 September 2023
Accepted 18 October 2023

Keywords:
Circadian rhythm
Eveningness
Morningness
Insomnia
Chronotype
Sleep

ABSTRACT

Objectives: This study investigated (non)linear associations between different eveningness characteristics (bedtime, wake time, morning affect, and peak performance time) and insomnia symptoms (difficulties initiating sleep, difficulties maintaining sleep, and nonrestorative sleep) in a large general population sample.

Methods: The data came from digital surveys about insomnia (Minimal Insomnia Scale) and circadian preferences (Children's Chronotype Questionnaire/Composite Scale of Morningness) completed by the Dutch general population (37,389 participants aged 4-91 years, 42.4% men) in the Lifelines cohort substudy Comorbid Conditions of ADHD.

Results: Using generalized additive modeling, we found that different characteristics of eveningness related to insomnia either exponentially (later wake time/peak performance time, worse morning affect) or quadratically (early and late bedtime/midpoint of sleep). While difficulties initiating sleep and nonrestorative sleep were strongly associated with all eveningness characteristics, difficulties maintaining sleep related only to earlier bedtimes. These relationships were similar for men and women but varied partly in shapes and strengths across the lifespan. Additional analyses showed that bedtime and wake time were associated with insomnia symptoms only when their combination would result in an unusually long or short preferred time in bed.

Conclusion: The association between eveningness and insomnia symptoms highly depends on whether eveningness is reflected by daytime performance or sleep-wake time. The pattern and strength of these associations also vary depending on age and insomnia symptom, but less so on sex. Future sleep-related research and policies relying on circadian preferences should account for the nonlinearity, dimension/symptom-related specificity and age-related differences in the association between eveningness and insomnia symptoms.

© 2023 The Author(s). Published by Elsevier Inc. on behalf of National Sleep Foundation. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Introduction

Later circadian preferences, or "eveningness," have been consistently associated with insomnia symptoms, which include difficulties initiating and maintaining sleep and subsequent daytime dysfunction.[1-7] Furthermore, both insomnia symptoms and eveningness have been linked to the same adverse health outcomes, such as common mental and cardiometabolic disorders.[8-12]

Some earlier studies suggested that the direction, strength, and even presence of the association between circadian preferences and insomnia symptoms could differ when associating specific symptoms and dimensions.[13-18] For example, research on children and adolescents found that eveningness related to difficulties initiating but not maintaining sleep.[14,17] Moreover, results could depend on the operationalization of circadian preference. Whereas some measures specifically define eveningness as later sleep-wake times, most circadian preference questionnaires also include additional dimensions,

* Corresponding author: Dina Sarsembayeva, MRes, Hanzeplein 1 – Entrance 24 (Triade Bldg.), 9700 RB Groningen, the Netherlands. Tel.: +31649545649.
E-mail address: d.sarsembayeva@umcg.nl (D. Sarsembayeva).

https://doi.org/10.1016/j.sleh.2023.10.008
2352-7218/© 2023 The Author(s). Published by Elsevier Inc. on behalf of National Sleep Foundation. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

such as alertness and affective state in the morning.[18] Although insomnia symptoms were consistently associated with eveningness measured with multidimensional questionnaires, the results based on circadian preferences measured as sleep-wake time sometimes showed either no or a reverse relationship.[19-21] These differences across operationalizations along with the possible symptom specificity of the relationship between insomnia symptoms and circadian preferences may partially explain heterogeneity in earlier findings.

Another issue that may explain inconsistent findings is that earlier studies exclusively relied on linear models, whereas insomnia symptoms may be related to both extremely early and late circadian preferences. To illustrate, several studies showed that insomnia symptoms can also be associated with early circadian types, or a specific range of (extreme) eveningness scores.[3,20,22,23] Given the age and sex differences in prevalence of insomnia symptoms and normal developmental shifts in circadian preferences across the lifespan, the associations between circadian preferences and insomnia symptoms likely also differ for demographic subgroups.[24-26] However, current literature cannot provide enough evidence of such differences since most earlier studies recruited specific age groups such as adolescents and young adults from specific settings such as universities, clinics, or workplaces. Thus, despite the strong evidence of an association between insomnia symptoms and circadian preferences, the shape of this relationship for specific symptoms/dimensions and its generalizability to the population at large remain unclear.

This exploratory study aimed to refine our understanding of the relationship between insomnia symptoms and circadian preferences. The scarcity of large, representative samples in the literature has been addressed by including a large sample (N = 37,401) of the general population in the Netherlands with a wide age range (4-91 years) and a relatively balanced sex ratio (42.4% men). To focus on symptom/dimension-specific associations and account for the differences related to age and sex, our study investigated the associations between separate dimensions of circadian preferences and individual symptoms of insomnia. In addition, statistical models in our study allowed nonlinearity and accounted for age/sex differences in these associations.

Methods

Participants

Data came from an add-on study implemented in the Lifelines cohort by Dr Catharina Hartman and supported by the EU Consortium study “Comorbid Conditions of ADHD” (CoCA). Both Lifelines and CoCA were approved by the ethics committee of the University Medical Centre Groningen, and all participants or their legal representatives gave their informed consent in writing.

Lifelines is a multidisciplinary prospective population-based cohort study examining in a unique three-generation design the health and health-related behaviors of 167,729 persons living in the North of the Netherlands. It employs a broad range of investigative procedures in assessing the biomedical, sociodemographic, behavioral, physical and psychological factors which contribute to the health and disease of the general population, with a special focus on multimorbidity and complex genetics.[27] The first participants were recruited between 2006 and 2013, through their general practitioners (73% out of the total of 812 agreed to participate), with whom every Dutch resident is registered. In total, the sample included 24.5% of the 333,307 individuals asked by their general practitioner (aged 25-50 years), 70.2% of the 91,885 invited by their family members[a] (aged 6 months to 93 years), and 21,588 who self-registered through the Lifelines website. The participants with very severe psychiatric or physical illness, short life expectancy (< 5 years), and/or insufficient fluency of the informant in the Dutch language were excluded. The participants were followed from 2006 onwards, with repeated assessments every 5 years. Lifelines fairly represents the Northern Dutch general population, with small differences in demographics and general health.[28] A few notable differences include the overrepresentation of middle-aged adults (due to the recruitment strategy to enroll three generations of participants starting with the middle generation), a surplus of men among the elderly, and underrepresentation of immigrants and those with lower educational attainment.[28,29] More details about the study can be found in the Cohort Profile papers.[27,30]

The CoCA sample consists of 37,727 individuals aged 4-91 years. All Lifelines participants with internet access were asked to participate in the study between 2017 and 2019. Of those invited, 45% of adults, 15% of adolescents, and 33% of parents with children were enrolled in CoCA. Compared to the part of Lifelines who did not participate in CoCA, participants from the CoCA sample were somewhat younger (children), worked more hours, had more years of completed education and higher disposable monthly income (adults); the absolute differences in these characteristics, however, were small (see Supplementary Table A1). The differences in sex, prevalence of unemployment, and chronic diseases were negligible.

Measurements

Demographic and sleep characteristics were measured using digital surveys, reported by parents for children (aged 4-12 years) and self-reported by adults (≥18 years). Adolescents (13-17 years) reported insomnia symptoms themselves, and circadian preferences were reported by their parents. To ensure the comparability of effects across age groups, we used the same or very similar instruments for all participants.

All participants reported their sex as male or female and age in years. General health of the participants was described by the presence or absence of four common chronic conditions, including cardiovascular diseases, diabetes, high blood pressure, and chronic obstructive pulmonary disease. Educational attainment varied between the categories of not finishing primary education (1) to finishing a university degree (8). Household income was measured as net monthly salary in euro. For participants aged < 25 years, these variables were calculated as an average of their parents. Employment status[31] was classified as unemployed (all reasons except retirement), employed (paid work), or retired.

The description of the instruments and score calculation used to measure circadian preferences and insomnia symptoms are available in Table 1. Circadian preferences of adults were measured with Composite Scale of Morningness (CSM) that was validated for adolescents, young, middle-aged and older adults,[32-36] including shift workers.[37] CSM correlates with the Horne & Ostberg’s (r = 0.95) and Torsvall & Akerstedt’s morningness-eveningness questionnaires (r = 0.79) and is reliable (Cronbach’s alpha = 0.87). For children and adolescents, the Children’s ChronoType Questionnaire (CCTQ) scale was used, which is essentially a parent-report version of the CSM validated for children aged 2-11 years, which correlates with midpoint of sleep by actigraphy (r = 0.78) and has high test-retest reliability (r = 0.94).[38,39] Insomnia symptoms were measured with Minimal Insomnia Scale (MISS) that was validated for adolescents, young, middle-aged and older adults. MISS correlates with sleep quality (r = 0.76), is reliable (ICC = 0.79), and has cut-offs that agree with the ICD-10 insomnia diagnosis.[40-43] Parent-reported version of MISS used in children was not used before and, thus, not validated. The missing data concerning insomnia symptoms in adolescents were predicted based on their parent-reported results of the MISS. A comprehensive review of CSM and Children’s Chronotype Questionnaire’s morningness-eveningness scale

[a] Dependency among family members was low, and therefore, accounting for nesting was not necessary.

Table 1
Detailed description of the measuring instruments and variables used in the study

Subgroup/Variable name	Definition	Instrument	Unit and score range
Circadian preferences ("eveningness")	Personal preferences in sleep-wake and day activity timing considering the "feeling best" rhythm based on the four dimension scores (below)	For children and adolescents, parent-reported: the multi-item morningness-eveningness scale from the CCTQ; Adults, self-reported: CSM	Mean score: 0 ("extremely early")-4 ("extremely late")
(Preferred) Bedtime	Preferences in bedtime considering the "feeling best" rhythm		
(Preferred) Wake time	Preferences in wake time considering the "feeling best" rhythm		
(Negative) Morning affect	Affect and alertness after sleep and early in the morning		
Peak performance time	Peak time of physical and cognitive performance at daytime		
Insomnia symptoms	The severity of all individual insomnia symptoms (below)	Children: parent-reported MISS Adolescents and adults: MISS	Mean score: 0 ("no symptoms")-4 ("very severe")
Difficulties initiating sleep	Difficulties in starting sleep at desirable time		
Difficulties maintaining sleep	Difficulties maintaining sleep without awakening throughout the night		
Nonrestorative sleep	Feeling unrested after sleep		

CCTQ, Children's Chronotype Questionnaire; CSM, Composite Scale of Morningness; MISS, Minimal Insomnia Scale.

(CCTQ), and our reasoning behind the division into four dimensions, are included in the Supplementary Section 1. For direct comparability and easier interpretation, we reversed and recoded all item scores, so that the response scale for all items of MISS and CSM/CCTQ was the same (0-4 points), where higher scores reflect correspondingly more severe symptoms, or later circadian preferences (higher eveningness).

Statistical analyses

We performed all analyses in R Studio version 2022.12.0+353, R 4.2.2 for MacOS. Analyses were performed on data from each participant who completed sleep-related questionnaires, resulting in an analytical sample of N = 37,389 (99% of the original sample). As preliminary analyses, we calculated summary statistics and Spearman correlations for the demographic and sleep-related characteristics. For our main analyses, we used generalized additive modeling (GAM) to determine the presence and potential nonlinearity of the relationship between insomnia symptoms and eveningness across the lifespan. GAM estimates linear and nonlinear relationships using smooth functions that may take a variety of shapes, such as exponential or quadratic. Overfitting is prevented by minimizing the error and penalizing the degree of nonlinearity allowed in the model. The nonlinearity of the relationship between an outcome and a predictor is indicated by effective degrees of freedom (edf), where 1 represents a perfectly linear relationship, and higher values indicate more pronounced nonlinearity. The *p*-value indicates the statistical significance of the effect estimated in the model. We fit a series increasingly complex nonlinear models using the *mgcv* package.[44] In the simplest model, we predicted insomnia symptoms (outcome) by linear terms for sex, age, and eveningness (predictors). Next, we added nonlinear terms for age and eveningness, a nonlinear interaction between age and eveningness (tensor smooth), and modeled separate effects (smooths) for men and women to account for sex differences. In all models, we used the default number of basis functions (k): k = 10 for smooths and k = 17 for tensor interactions. We chose the final model based on the model fit test based on maximum likelihood.[45] A detailed script and models output are available in Supplementary Materials on the Open Science Framework (https://osf.io/eq8dt/files/osfstorage).

Finally, we used GAM in the follow-up analyses to test: (1) the effects of bedtime, wake time, and their interaction on insomnia symptoms, and (2) the effects of midpoint of sleep, time in bed, and their interaction on insomnia symptoms.

Table 2
Demographic and sleep-related characteristics of the sample

	N = 37,389
Age (y)	48.84 (15.81)
Educational attainment	5.68 (1.49)
Employment status	
Unemployed	3146 (8.4%)
Employed	19,139 (51.2%)
Retired	4025 (10.8%)
Household income (euro)	1704.27 (522.55)
Cardiovascular disease	
No	30,835 (82.5%)
Yes	845 (2.3%)
High blood pressure	
No	25,382 (67.9%)
Yes	7265 (19.4%)
Diabetes	
No	34,734 (92.9%)
Yes	1379 (3.7%)
Chronic obstructive pulmonary disease	
No	8684 (23.2%)
Yes	1098 (2.9%)
Insomnia (categories[a])	
None	6861 (18.4%)
Mild	15,061 (40.3%)
Severe	3585 (9.6%)
Insomnia symptoms	0.71 (0.76)
- Difficulties initiating sleep	0.53 (0.85)
- Difficulties maintaining sleep	0.81 (0.96)
- Nonrestorative sleep	0.80 (1.00)
Eveningness	1.43 (0.58)
- Bedtime	1.88 (0.56)
- Wake time	1.79 (0.78)
- Morning affect	1.04 (0.82)
- Peak performance time	1.22 (0.87)

The values in the cells show means and standard deviations in parentheses for continuous variables and number of observations and the proportion in the whole sample in parentheses for categorical variables.

[a] The categories were created by cutting off the MISS sum-scores into those without any insomnia symptoms (scores of 0), mild symptoms (scores between 0 and 6-7), and severe symptoms (also known as "possible clinical insomnia" the cut-offs as recommended in the literature were ≥6 points for adolescents and young/middle-aged adults and ≥7 points for older adults).

Results

Sample characteristics and correlations between sleep-related variables

Our sample included 15,837 men and 21,552 women aged 4-91 years (see all sample characteristics in Table 2 and per age-sex subgroup, in Supplementary Table A2). Most participants had no or

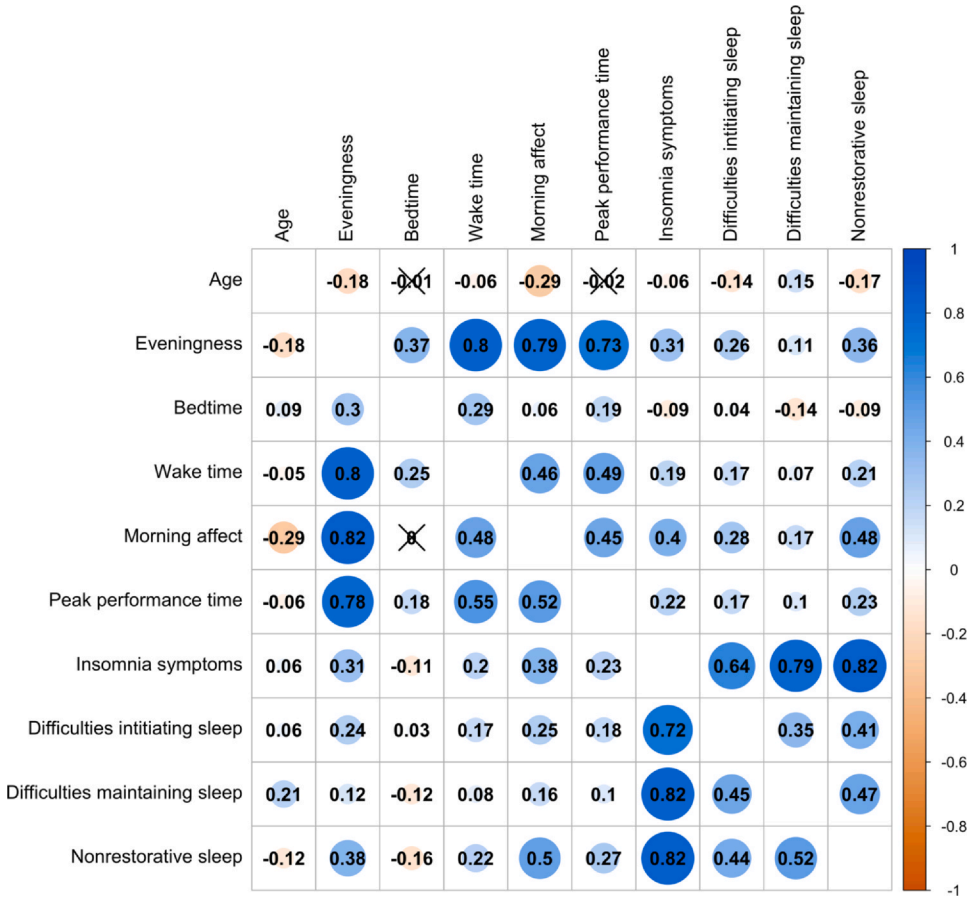

Fig. 1. Correlations between age, insomnia symptoms, and eveningness dimensions in men (upper right) and women (bottom left). Coefficients (Pearson's rho) indicate the strength of the linear relationship between the two given variables. Colors correspond to a positive (blue) or negative (orange/red) relationship, with more intense coloring indicating a stronger relationship. The correlations that are not statistically significant (at the alpha-level 0.05) are indicated by a black cross

very low severity of insomnia symptoms; women reported higher scores than men. Among three individual insomnia symptoms, the severity was higher for difficulties maintaining sleep and nonrestorative sleep compared to difficulties initiating sleep. Circadian preferences in children, middle-aged and older adults were earlier than that of adolescents and young adults. When assessed as dimensions of bedtime and wake time, circadian preferences tended to be considerably later than when assessed by morning affect and peak performance time. All sleep characteristics were significantly correlated with each other, except for morning affect and bedtime in women (see Fig. 1).

Nonlinear relationships between insomnia symptoms and eveningness

The models with nonlinear terms more optimally fit the data compared to the linear models for all combinations of the related insomnia symptoms and eveningness dimensions. Further, accounting for age and sex-related differences in the association between insomnia symptoms and eveningness dimensions significantly improved model fit (for details, see Supplementary Table A3). For both men and women, all insomnia symptoms were exponentially related to eveningness in both men and women (see Fig. 2). Those with relatively early preferences had low severity of insomnia symptoms, whereas those with intermediate to later circadian preferences (1 point and higher) had increasing symptom severity. See Table 3 for exact model parameters and estimates. The same exponential pattern applied to the relationships between the three insomnia symptoms and the eveningness dimensions of wake time, morning affect, and peak performance time. Unlike other eveningness dimensions, bedtime had either a quadratic or reversed exponential relationship with insomnia symptoms: U-shaped for nonrestorative sleep, J-shaped for difficulties initiating sleep, and L-shaped for difficulties maintaining sleep). The relationship with all insomnia symptoms was stronger for morning affect compared to the other eveningness dimensions. The strength and shape of the relationship between eveningness dimensions and insomnia symptoms were similar for men and women but differed considerably with age (see Fig. 3A and B). The 2D- and 3D-visualization of the relationships between eveningness dimensions, age, and insomnia symptoms can be found in Fig. 3 and Supplementary Fig. 1A.

Follow-up analyses

Given that bedtime and wake time were related to insomnia symptoms differently, we decided to explore the relationship with these sleep-wake characteristics further. Specifically, we analyzed the interrelation between bedtime, wake time, and insomnia symptoms and found that the severity of all insomnia symptoms was greater in those who preferred either earlier bedtimes and later wake times or later bedtime and earlier wake times (see Table A4). Therefore, bedtime and wake time were associated with more severe insomnia symptoms only in persons with a relatively long, and to a lesser extent short, preferred time in bed (see Fig. A2). When combining bedtime and wake time into midpoint of sleep, we found that

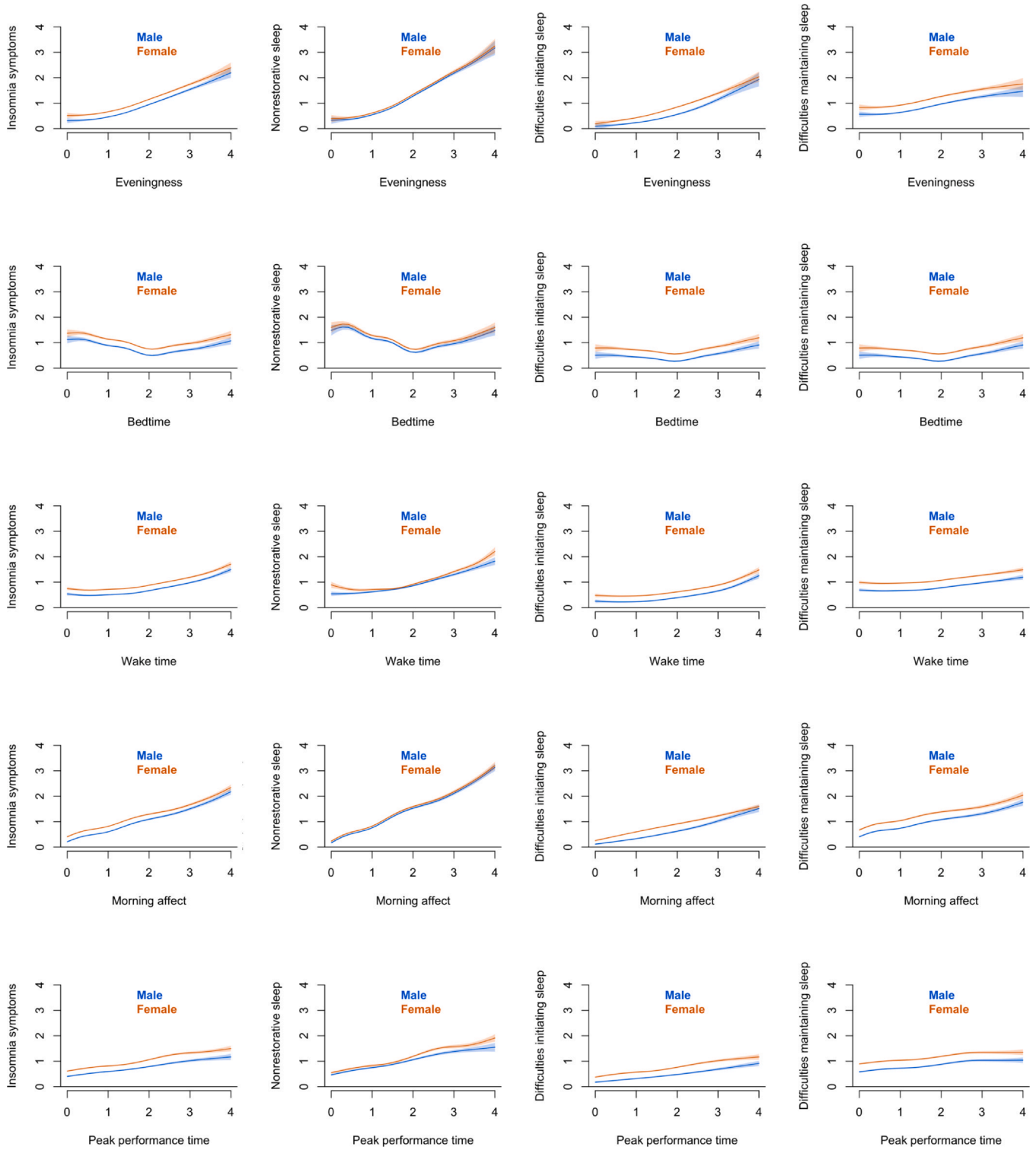

Fig. 2. Nonlinear differences in the severity of insomnia symptoms depending on eveningness in men (blue) and women (orange). Y-axis depicts the severity of insomnia symptoms (total score and three individual symptoms) and X-axis depicts eveningness scores (total and four individual dimensions)

those with later midpoints of sleep combined with a long time in bed generally had the most severe nonrestorative sleep and difficulties initiating (but not maintaining) sleep (see Table A5 and Fig. A3). In the sample stratified by employment status, the associations between circadian preferences and insomnia symptoms were stronger in the unemployed and weaker in the retired compared to the employed (see Fig. A4), and differed with age only for the employed (see Table A6).

Discussion

Our study demonstrated that the association between insomnia symptoms and eveningness is distinctly nonlinear (exponential or quadratic) in both men and women in the general population.

The strength and shape of this association differed across insomnia symptoms and eveningness dimensions. Specifically, difficulties maintaining sleep generally showed weaker relations with

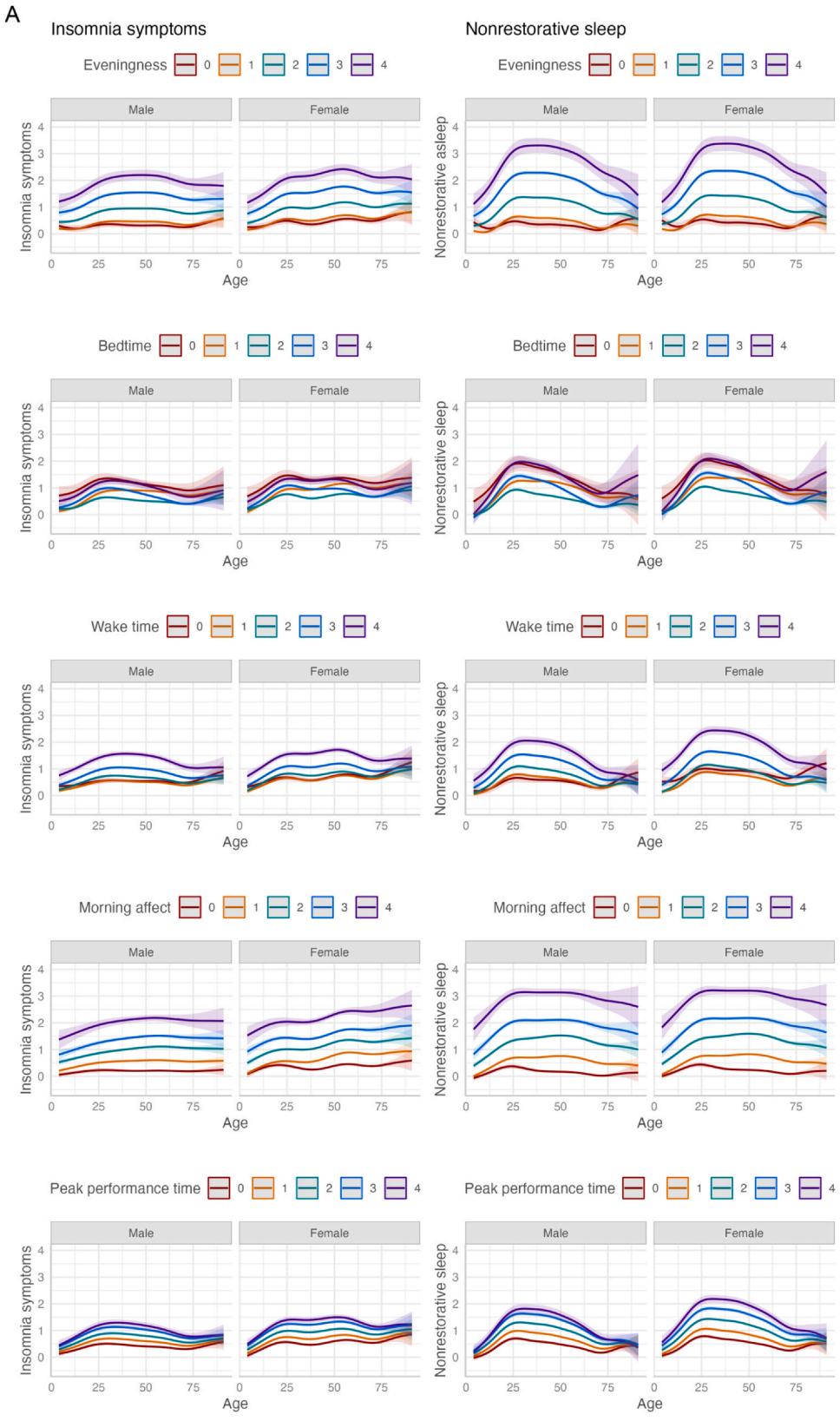

Fig. 3. A. Nonlinear relationships between insomnia symptoms and circadian preferences in men and women across the lifespan. The colored lines show the estimated severity of total insomnia symptoms and nonrestorative sleep depending on (A) total eveningness and its four dimensions of (B) bedtime, (C) wake time, (D) morning affect, and (E) peak performance time, from 0 (extremely early preferences) to 4 (extremely late preferences). Shaded areas over the colored lines indicate 95% confidence intervals. B. Nonlinear relationships between insomnia symptoms and circadian preferences in men and women across the lifespan. The colored lines show the estimated severity of difficulties initiating and maintaining sleep depending on (A) total eveningness and its four dimensions of (B) bedtime, (C) wake time, (D) morning affect, and (E) peak performance time, from 0 (extremely early preferences) to 4 (extremely late preferences). Shaded areas over the colored lines indicate 95% confidence intervals

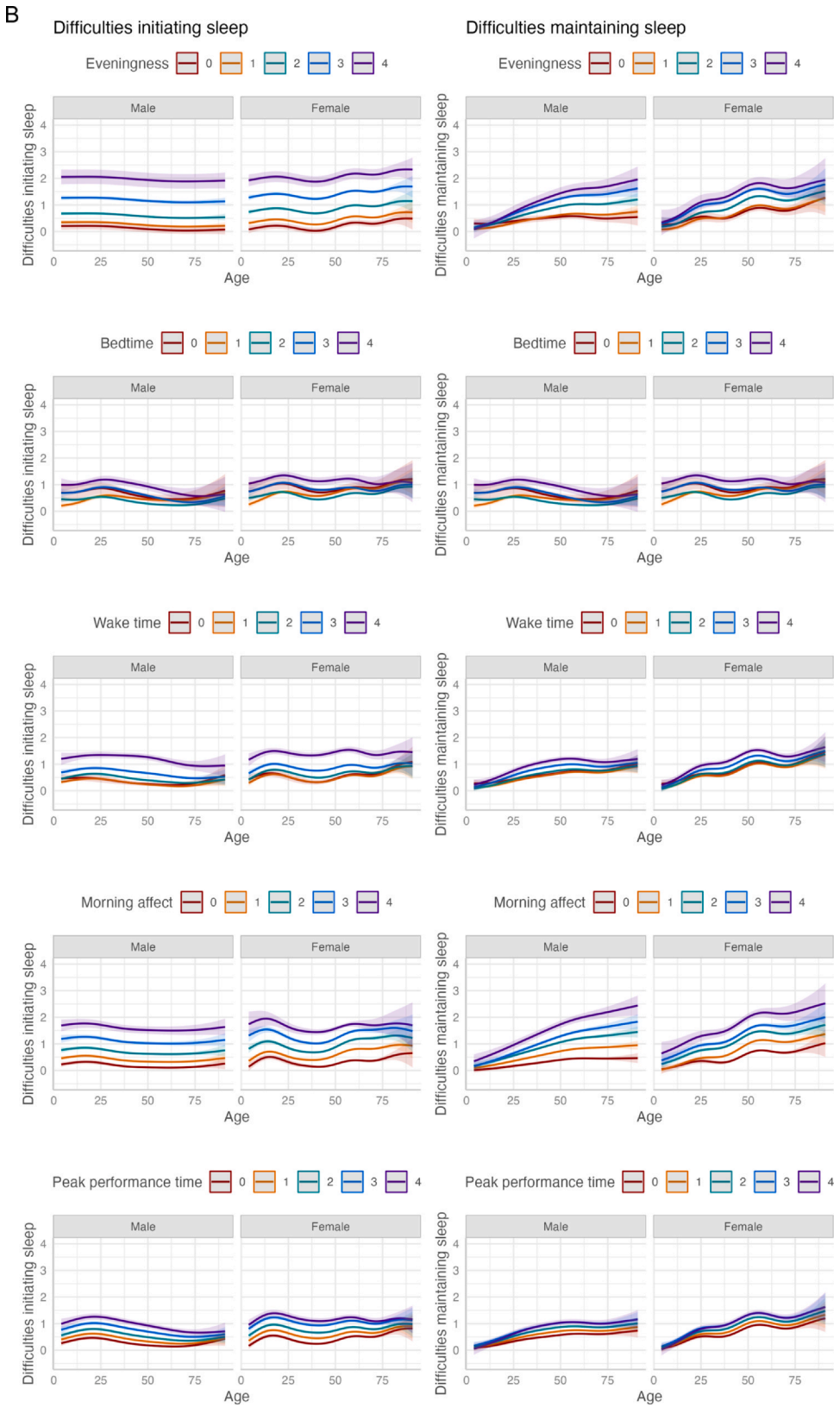

Fig. 3. (*continued*)

eveningness dimensions compared to other insomnia symptoms. Further, the relation between insomnia symptoms and bedtime was different (quadratic or reverse exponential) compared to the relations between insomnia symptoms and other eveningness dimensions (exponential). The relationship between the midpoint of sleep and all insomnia symptoms resembled that of bedtime, and not wake time. The associations between most symptoms and dimensions were similar for men and women, but differed in strength across the lifespan. The follow-up analyses demonstrated that preferred bedtime and wake time were associated with insomnia

Table 3
Results of the generalized additive models of the effects of eveningness dimensions, age, and their interaction on insomnia symptoms in men and women

Outcome/Predictor	Age	Predictor	Age – predictor interaction
Insomnia			
Eveningness	7.018^{***}/7.727^{***}	5.490^{***}	2.995^{***}
Bedtime	7.312^{***}/7.778^{***}	7.554^{***}	11.432^{***}
Wake time	6.592^{***}/7.627^{***}	6.408^{***}	4.954^{***}
Morning affect	4.759^{***}/7.425^{***}	7.308^{***}	5.364^{***}/6.564^{***}
Peak performance time	6.609^{***}/7.570^{***}	1.008^{***}/5.271^{***}	3.116^{***}
Nonrestorative sleep			
Eveningness	8.410^{***}	6.074^{***}	3.705^{***}
Bedtime	8.310^{***}	8.059^{***}	11.540^{***}
Wake time	8.213^{***}	4.266^{***}/6.803^{***}	5.610^{***}
Morning affect	7.517^{***}	7.560^{***}	8.501^{***}
Peak performance time	8.198^{***}	4.261^{***}/5.689^{***}	3.459^{***}
Difficulties initiating sleep			
Eveningness	3.378^{***}/7.276^{***}	4.211^{***}/3.905^{***}	Not in the model[a]
Bedtime	6.336^{***}/7.456^{***}	6.296^{***}	10.257^{***}
Wake time	5.359^{***}/7.638^{***}	6.006^{***}	$6.187^{0.019}$
Morning affect	5.271^{***}/7.818^{***}	3.645^{***}/1.006^{***}	$1.235^{0.316}$/7.643^{***}
Peak performance time	5.865^{***}/7.732^{***}	2.334^{***}/4.517^{***}	5.865^{***}
Difficulties maintaining sleep			
Eveningness	5.182^{***}/7.595^{***}	4.588^{***}	1.766^{***}/4.282^{***}
Bedtime	6.336^{***}/7.456^{***}	6.296^{***}	10.257^{***}
Wake time	6.413^{***}/7.565^{***}	4.699^{***}	2.620^{***}
Morning affect	3.994^{***}/7.401^{***}	6.779^{***}	1.586^{***}/5.884^{***}
Peak performance time	5.005^{***}/7.495^{***}	5.013^{***}	$2.861^{0.019}$

The values in the cells show the effective degrees of freedom (*edf*), which indicate the degree of nonlinearity, and the corresponding *p*-value as a superscript, which indicates statistical significance. In the case when the effect is not statistically significant ($p > .05$), the exact *p*-value is indicated, and when significant, the asterisks correspond to $p < .05$ (*), $p < .01$ (**), or $p < .001$ (***). If the nonlinear effect was estimated separately for men and women, the value on the left corresponds to men, and on the right, to women, separated with a slash.

[a] The term was not included in the model because its addition did not improve the model fit.

symptoms only when their combination would result in abnormally long (or, to a lesser extent, short) time in bed. Additionally, these associations were weak in the retired and stronger in the unemployed compared to the employed participants.

Our study confirmed that eveningness dimensions are related to most insomnia symptoms in the general population of all ages and both sexes. Complementing earlier findings in children and adolescents, we showed that difficulties initiating sleep and nonrestorative sleep related to higher total eveningness and also all its dimensions throughout the lifetime.[14,17,23,46,47] Similarly to early morning/night awakenings not correlating with eveningness, difficulties maintaining sleep in our study were very weakly associated with eveningness and all its dimensions except morning affect.[13,14] Further, we demonstrated the potential nonlinearity of the relationship between eveningness and insomnia symptoms that was indirectly suggested by several previous studies.[3,20,22,23] For instance, one study reported that earlier melatonin rhythms coincide with early morning awakenings and another found that later bedtime preferences relate to more severe insomnia.[15,16] In our study, insomnia symptoms were generally associated with later preferences in most eveningness dimensions, but earlier bedtimes were also associated with increased insomnia symptoms severity. The quadratic relationship between these insomnia symptoms and bedtime/wake time in our findings explained why in some studies, insomnia symptoms had no linear relationship with eveningness measured as sleep-wake time or related to earlier preferences instead.[19–21,48] Specifically, it is possible that the opposite directions of this relationship (negative at some values of sleep time, and positive at others) could potentially cancel out the linear trend. Our follow-up analyses suggested that the association between specific bedtimes/wake times and insomnia symptoms are likely driven by time in bed: insomnia symptoms are most severe when the bedtime/wake time combinations would result in abnormally long, or short, time in bed. This finding is supported by the previously described symptom-specific quadratic relationship between time in bed and prevalence of insomnia symptoms.[24] Longer time in bed is often observed in those with insomnia symptoms, likely as compensatory behavior.[49] Thus, our study confirmed the nonlinearity of the association between eveningness and insomnia symptoms and variation in its shapes and direction depending on the dimensions, symptoms, age, and sex.

Dimensions that describe sleep-wake time (bedtime and wake time) and daytime performance (morning affect and peak performance time) were related to insomnia symptoms in our study in two distinct patterns. This distinction suggested that the associations between circadian preference and insomnia symptoms strongly depend on the operationalization of circadian preference, and hence may be driven by different mechanisms. Panjeh et al have proposed that different dimensions of circadian preference may measure independent processes of sleep regulation, which mostly measure sleep homeostasis: bedtime mostly reflects sensitivity to build-up of sleep pressure, morning affect reflects the efficiency of dissipating sleep pressure, and peak performance time might reflect subjective circadian amplitude.[50] The independence of these processes was supported by our data, for example, the fact that bedtime and morning affect are not correlated (see Fig. 1). Furthermore, the frequent overlap between most of circadian preference dimensions and insomnia symptoms further supported the hypothesis that some dimensions of circadian preference, such as morning affect, might reflect not the preferred timing of sleep but rather problems in sleep homeostasis. Since the timing driven by homeostatic sleep regulation, that is, sleep drive, often coincides with circadian regulation of sleep, these constructs are highly correlated. However, in the case when sleep homeostasis is disrupted, such as in insomnia symptoms, the circadian preference scores may no longer be a good proxy of the preferred circadian timing. For example, self-reported, but not objectively measured, circadian preferences differ between those with and without depression and anxiety, likely due to sleep misperception observed in these mental disorders.[20] Furthermore, nonrestorative sleep likely mediates the relationship between self-reported circadian preference and difficulties initiating and maintaining sleep in adolescents.[51] Thus, the current findings supported a few earlier studies showing that self-reported circadian preferences

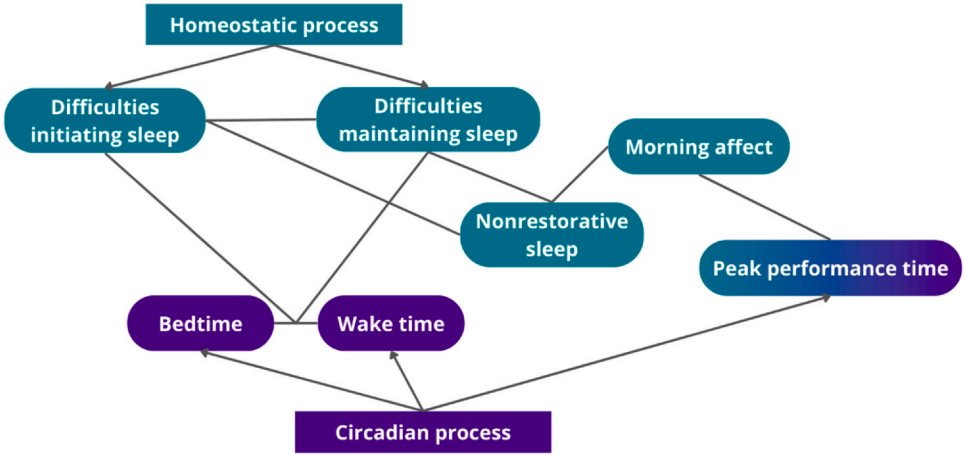

Fig. 4. Conceptual framework of the associations between circadian preferences and insomnia symptoms proposed in the Discussion section. The associations between circadian preferences and insomnia symptoms are likely driven by two different processes of sleep regulation. The homeostatic process, when disrupted, is leading to difficulties initiating and maintaining sleep, which in turn lead to nonrestorative sleep. Nonrestorative sleep will result in more negative morning affect, and consecutively, influence peak performance time during daytime, likely delaying it. The circadian process determines bedtime, wake time, and peak performance time, which usually coincide with the sleep and activity timing that are driven by the homeostatic sleep process (the buildup and resolving of sleep need) and are more or less accurately reflected by individual circadian preferences. However, in the presence of insomnia symptoms, circadian preferences will be highly influenced by the divergence between the circadian and homeostatic process, and thus, more likely to reflect a higher sleep need due to nonrestorative sleep, resulting in the bedtime and wake time preferences that would result in longer time in bed (delayed bedtime and wake time, or earlier bedtime), and worse mental and physical functioning at daytime (reflected by delayed peak performance time and negative morning affect)

are more strongly reflected by daytime functioning rather than sleep-wake time, and the divergence between these two global dimensions can be strongly affected by sleep problems (see Fig. 4).[18,20]

This distinction between eveningness dimensions has several implications important for future research and healthcare practices. First, self-assessed eveningness and insomnia symptoms were frequently associated in earlier research likely because they both reflect the same processes of (homeostatic) sleep regulation. Second, total scores derived from multidimensional instruments, such as CSM/CCTQ in our study, may not accurately assess circadian preferences in populations with sleep problems, in whom circadian and homeostatic processes diverge. Third, other health-related outcomes may be associated with eveningness only through specific dimensions and in the presence of sleep problems. For example, Merikanto et al found that mental health problems were associated with the morning affect-based eveningness score, but not with sleep-wake time, and this association was fully mediated by insufficient sleep.[9] Additionally, weak or absent associations between circadian timing and insomnia symptoms in the retired participants in our follow up analyses suggested that sleep may not be disrupted in those without strict societal demands for certain sleep-wake times. Altogether, these conclusions underline the need for an explicit distinction between different definitions of eveningness and for instruments that could be more precise in measuring circadian preferences in the presence of sleep problems.

Our study design had several limitations that require caution when interpreting the findings. First, insomnia and circadian preferences are individual experiences that can be under- or overestimated due to either sleep misperception associated with sleep problems[20] or informant differences.[52,53] For example, parents can often underestimate bedtimes and overestimate wake times of children[53] and adolescents,[52] which could have affected the associations established in our study for these age groups. However, lifespan differences in sleep characteristics in our study were similar to those based on self-reported and actigraphy-based data, suggesting that our parent-report data were rather accurate. Second, the cross-sectional nature of our study did not allow us to study potential bidirectionality of the association between insomnia and eveningness. We hope that future research will use longitudinal data to test the direction and temporal patterns in these associations. Third, our study sample only included individuals from the general (northern) Dutch population, and the found relationships between insomnia symptoms and circadian preferences may not generalize to other populations. For example, the relationship may differ in the countries where the population has more sleep problems than in the Netherlands or differs in average circadian preferences due to the difference in latitude.[54,55] Relatedly, the generalizability to the population with insomnia disorder is limited, since the symptoms captured by MISS do not include all necessary criteria of insomnia disorder, such as daytime dysfunction and early morning awakenings.[49] Sleep differences between the participants and non-participants of CoCA also could not be compared; given the similar prevalence in chronic diseases in these samples, the prevalence of insomnia is likely similar as well. Lastly, the associations between circadian preferences and insomnia symptoms are likely affected by other third factors besides age and sex. In addition to several factors in our follow-up analyses (including time-in-bed and employment status), circadian preferences and insomnia symptoms are both linked to a wide range of mental and physical disorders, daytime functioning, socioeconomic status and gender identities.[8-12,24,56,57] Future research is required to address the role of such factors in sleep. All in all, the limitations mentioned above could not majorly affect the overall conclusions drawn from our findings.

To conclude, our study showed that insomnia symptoms are usually equally low in those with early to intermediate preferences when measuring eveningness by daytime performance but can relate to both unusually early and late preferences if eveningness is reflected by sleep-wake time. Coupled with previous research, our findings suggested that not preferred bedtime and wake time per se, but rather their interplay resulting in certain time in bed and daytime performance, determine the association between eveningness and insomnia symptoms. Therefore, future research and health-related policies that use knowledge about circadian preference, insomnia symptoms, and related health outcomes need to account for the likely nonlinearity, dimension/symptom-related specificity and age/sex-related differences of these associations.

Author contributions

DS, MS, CH: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization,

Roles/Writing – original draft, Writing – review & editing. RDCM: Conceptualization, Methodology, Formal analysis, Writing – review & editing.

Funding

The research leading to these results received funding from the European Community's Horizon 2020 Programme (H2020/2014-2020) under grant agreement no. 667302 (CoCA), 728018 (Eat2beNICE) and no. 965381 (TIMESPAN). The Lifelines initiative has been made possible by subsidy from the Dutch Ministry of Health, Welfare and Sport, the Dutch Ministry of Economic Affairs, the University Medical Center Groningen (UMCG), Groningen University and the Provinces in the North of the Netherlands (Drenthe, Friesland, Groningen).

Declaration of conflicts of interest

None.

Acknowledgments

The authors wish to acknowledge the services of the Lifelines Cohort Study, the contributing research centers delivering data to Lifelines, and all the study participants.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.sleh.2023.10.008.

References

1. Alvaro PK, Roberts RM, Harris JK. The independent relationships between insomnia, depression, subtypes of anxiety, and chronotype during adolescence. *Sleep Med.* 2014;15:934–941.
2. Choi SJ, Song P, Suh S, Joo EY, Lee SI. Insomnia symptoms and mood disturbances in shift workers with different chronotypes and working schedules. *J Clin Neurol.* 2020;16:108–115.
3. Bradford DRR, Biello SM, Russell K. Insomnia symptoms mediate the association between eveningness and suicidal ideation, defeat, entrapment, and psychological distress in students. *Chronobiol Int.* 2021;38:1397–1408.
4. Lin CY, Imani V, Griffiths MD, et al. Temporal associations between morningness/eveningness, problematic social media use, psychological distress and daytime sleepiness: mediated roles of sleep quality and insomnia among young adults. *J Sleep Res.* 2021;30:e13076.
5. Hairston IS, Shpitalni R. Procrastination is linked with insomnia symptoms: the moderating role of morningness-eveningness. *Pers Individ Dif.* 2016;101:50–56.
6. Simor P, Zavecz Z, Pálosi V, Török C, Köteles F. The influence of sleep complaints on the association between chronotype and negative emotionality in young adults. *Chronobiol Int.* 2015;32:1–10.
7. Suh S, Ryu H, Kim S, Choi S, Joo EY. Using mid-sleep time to determine chronotype in young adults with insomnia-related symptoms. *Sleep Med Res.* 2017;8:107–111.
8. Lotti S, Pagliai G, Colombini B, Sofi F, Dinu M. Chronotype differences in energy intake, cardiometabolic risk parameters, cancer, and depression: a systematic review with meta-analysis of observational studies. *Adv Nutr.* 2022;13:269–281.
9. Merikanto I, Partonen T. Eveningness increases risks for depressive and anxiety symptoms and hospital treatments mediated by insufficient sleep in a population-based study of 18,039 adults. *Depress Anxiety.* 2021;38:1066–1077.
10. Hertenstein E, Feige B, Gmeiner T, et al. Insomnia as a predictor of mental disorders: a systematic review and meta-analysis. *Sleep Med Rev.* 2019;43:96–105.
11. Jarrin DC, Alvaro PK, Bouchard MA, et al. Insomnia and hypertension: a systematic review. *Sleep Med Rev.* 2018;41:3–38.
12. Zhang Y, Jiang X, Liu J, Lang Y, Liu Y. The association between insomnia and the risk of metabolic syndrome: a systematic review and meta-analysis. *J Clin Neurosci.* 2021;89:430–436.
13. Ong JC, Huang JS, Kuo TF, Manber R. Characteristics of insomniacs with self-reported morning and evening chronotypes. *J Clin Sleep Med.* 2007;3:289–294.
14. Giannotti F, Cortesi F, Sebastiani T, Ottaviano S. Circadian preference, sleep and daytime behaviour in adolescence. *J Sleep Res.* 2002;11:191–199.
15. Lack LC, Mercer JD, Wright H. Circadian rhythms of early morning awakening insomniacs. *J Sleep Res.* 1996;5:211–219.
16. Morris M, Lack L, Dawson D. Sleep-onset insomniacs have delayed temperature rhythms. *Sleep.* 1990;13:1–14.
17. Sun W, Kwok NTT, Chan NY, et al. Associations of circadian factors with insomnia symptoms and emotional and behavioral problems among school-age children. *J Clin Sleep Med.* 2021;17:2107–2114.
18. Di Milia L, Bohle P. Morningness or morning affect? A short composite scale of morningness. *Chronobiol Int.* 2009;26:494–509.
19. Birling Y, Li G, Jia M, et al. Is insomnia disorder associated with time in bed extension? *Sleep Sci.* 2020;13:215–219.
20. Difrancesco S, Lamers F, Riese H, et al. Sleep, circadian rhythm, and physical activity patterns in depressive and anxiety disorders: a 2-week ambulatory assessment study. *Depress Anxiety.* 2019;36:975–986.
21. Antypa N, Verkuil B, Molendijk M, et al. Associations between chronotypes and psychological vulnerability factors of depression. *Chronobiol Int.* 2017;34:1125–1135.
22. Hemmati-Maslakpak M, Mollazadeh F, Jamshidi H. The predictive power of sleep quality by morning-evening chronotypes, job satisfaction, and shift schedule in nurses: a cross-sectional study. *Iran J Nurs Midwifery Res.* 2021;26:127–132.
23. Eid B, Bou Saleh M, Melki I, et al. Evaluation of chronotype among children and associations with BMI, sleep, anxiety, and depression. *Front Neurol.* 2020;11:416.
24. Kocevska D, Lysen TS, Dotinga A, et al. Sleep characteristics across the lifespan in 1.1 million people from the Netherlands, United Kingdom and United States: a systematic review and meta-analysis. *Nat Hum Behav.* 2021;5:113–122.
25. Randler C, Faßl C, Kalb N. From Lark to Owl: developmental changes in morningness-eveningness from new-borns to early adulthood. *Sci Rep.* 2017;7:45874.
26. Crowley SJ, Wolfson AR, Tarokh L, Carskadon MA. An update on adolescent sleep: new evidence informing the perfect storm model. *J Adolesc.* 2018;67:55–65.
27. Scholtens S, Smidt N, Swertz MA, et al. Cohort Profile: LifeLines, a three-generation cohort study and biobank. *Int J Epidemiol.* 2015;44:1172–1180.
28. Klijs B, Scholtens S, Mandemakers JJ, et al. Representativeness of the LifeLines Cohort Study. *PLoS One.* 2015;10:e0137203.
29. Age composition and male/female surplus in the Netherlands (1950–2023). *Statistics Netherlands*. Accessed April 2, 2023. Available at: ⟨https://www.cbs.nl/en-gb/visualisations/dashboard-population/population-pyramid⟩.
30. Sijtsma A, Rienks J, van der Harst P, et al. Cohort Profile Update: Lifelines, a three-generation cohort study and biobank. *Int J Epidemiol.* 2022;51(5):e295–e302. https://doi.org/10.1093/ije/dyab257
31. Broekstra R, Aris-Meijer J, Maeckelberghe E, Stolk R, Otten S. Demographic and prosocial intrapersonal characteristics of biobank participants and refusers: the findings of a survey in the Netherlands. *Eur J Hum Genet.* 2021;29:11–19.
32. Smith CS, Reilly C, Midkiff K. Evaluation of three circadian rhythm questionnaires with suggestions for an improved measure of morningness. *J Appl Psychol.* 1989;74(5):728–738. https://doi.org/10.1037/0021-9010.74.5.728
33. Caci H, Adan A, Bohle P, et al. Transcultural properties of the composite scale of morningness: the relevance of the "morning affect" factor. *Chronobiol Int.* 2005;22:523–540.
34. Randler C. Validation of the full and reduced Composite Scale of Morningness. *Biol Rhythm Res.* 2009;40:413–423.
35. Morin AJS, Arens AK, Tran A, Caci H. Exploring sources of construct-relevant multidimensionality in psychiatric measurement: a tutorial and illustration using the Composite Scale of Morningness. *Int J Methods Psychiatr Res.* 2016;25:277–288.
36. Jankowski KS. Composite Scale of Morningness: psychometric properties, validity with Munich ChronoType Questionnaire and age/sex differences in Poland. *Eur Psychiatry.* 2015;30:166–171.
37. Greenwood KM. Long-term stability and psychometric properties of the Composite Scale of Morningness. *Ergonomics.* 1994;37(2):377–383. https://doi.org/10.1080/00140139408963653
38. Werner H, Lebourgeois MK, Geiger A, Jenni OG. Assessment of chronotype in four- to eleven-year-old children: reliability and validity of the Children's Chronotype Questionnaire (CCTQ). *Chronobiol Int.* 2009;26:992–1014.
39. Simpkin CT, Jenni OG, Carskadon MA, et al. Chronotype is associated with the timing of the circadian clock and sleep in toddlers. *J Sleep Res.* 2014;23:397–405.
40. Hellström A, Hagell P, Fagerström C, Willman A. Measurement properties of the Minimal Insomnia Symptom Scale (MISS) in an elderly population in Sweden. *BMC Geriatr.* 2010;10:84.
41. Broman J-E, Smedje H, Mallon L, Hetta J. The Minimal Insomnia Symptom Scale (MISS). *Ups J Med Sci.* 2008;113:131–142.
42. Westergren A, Broman JE, Hellström A, et al. Measurement properties of the minimal insomnia symptom scale as an insomnia screening tool for adults and the elderly. *Sleep Med.* 2015;16:379–384.
43. Hedin G, Garmy P, Norell-Clarke A, et al. Measurement properties of the minimal insomnia symptom scale (MISS) in adolescents. *Sleep Sci Pract.* 2022;6:1–14.
44. Wood SN. *Generalized Additive Models: An Introduction with R.* 2nd ed CRC Press; 2017.
45. Wieling M. Analyzing dynamic phonetic data using generalized additive mixed modeling: a tutorial focusing on articulatory differences between L1 and L2 speakers of English. *J Phon.* 2018;70:86–116. https://doi.org/10.1016/j.wocn.2018.03.002
46. Chan JWY, Lam SP, Li SX, et al. Eveningness and insomnia: independent risk factors of nonremission in major depressive disorder. *Sleep.* 2014;37:911–917.
47. Becker SP, Kapadia DK, Fershtman CEM, Sciberras E. Evening circadian preference is associated with sleep problems and daytime sleepiness in adolescents with ADHD. *J Sleep Res.* 2020;29:e12936.
48. Mozafari A, Tabaraie M, Tahrodi MHM. Morningness-eveningness chronotypes, insomnia and sleep quality among medical students of Qom. *J Sleep Sci.* 2016;1:67–73.

49. Riemann D, Benz F, Dressle RJ, et al. Insomnia disorder: state of the science and challenges for the future. *J Sleep Res.* 2022. https://doi.org/10.1111/jsr.13604
50. Panjeh S, Pompeia S, Archer SN, et al. What are we measuring with the morningness-eveningness questionnaire? Exploratory factor analysis across four samples from two countries. *Chronobiol Int.* 2021;38:234–247.
51. Tutek J, Albright AE, Lichstein KL. Nonrestorative sleep mediates eveningness and insomnia severity. *Sleep Biol Rhythms.* 2019;17:73–78.
52. Short MA, Gradisar M, Lack LC, Wright HR, Chatburn A. Estimating adolescent sleep patterns: parent reports versus adolescent self-report surveys, sleep diaries, and actigraphy. *Nat Sci Sleep.* 2013;5:23–26.
53. Mazza S, Bastuji H, Rey AE. Objective and subjective assessments of sleep in children: comparison of actigraphy, sleep diary completed by children and parents' estimation. *Front Psychiatry.* 2020;11:495.
54. Soldatos CR, Allaert FA, Ohta T, Dikeos DG. How do individuals sleep around the world? Results from a single-day survey in ten countries. *Sleep Med.* 2005;6:5–13.
55. Randler C, Rahafar A. Latitude affects Morningness-Eveningness: evidence for the environment hypothesis based on a systematic review. *Sci Rep.* 2017;7:39976.
56. Sosso FE, Khoury T. Socioeconomic status and sleep disturbances among pediatric population: a continental systematic review of empirical research. *Sleep Sci.* 2021;14:245–256.
57. Levenson JC, Thoma BC, Hamilton JL, Choukas-Bradley S, Salk RH. Sleep among gender minority adolescents. *Sleep.* 2021;44.