

Non-Right Handedness is Associated with More Time Awake After Sleep Onset and Higher Daytime Sleepiness Than Right Handedness: Objective (Actigraphic) and Subjective Data from a Large Community Sample

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Purpose: Handedness has been linked to various physiological and pathological phenomena including memory function and psychiatric disorders. Also for sleep, several studies have reported associations. However, large-scale studies including a broad age span of participants and studies analyzing women and men separately are lacking.

Methods: Therefore, objective sleep data were determined using at-home actigraphy from 1764 healthy participants (18 to 80 years, 908 women), averaging five consecutive nights. In addition, subjective sleep-related data were captured by self-report diaries, the Pittsburgh Sleep Quality Index (PSQI), the Epworth Sleepiness Scale (ESS) and the Morningness-Eveningness-Questionnaire (MEQ). Handedness was determined with the Edinburgh Handedness Inventory (EHI) providing information on the *direction* (left vs right) and the *degree* of handedness (strong vs weak). To address the potential endocrine effects, premenopausal women (≤ 45 years) and postmenopausal women (≥ 55 years) were analyzed separately. This was also done for men.

Results: The degree and direction of handedness were correlated with “wake after sleep onset” (WASO) in the total sample and all women (the more right-handed/lateralized the shorter WASO). In postmenopausal women, additionally, time in bed (TIB) and total sleep time (TST) were correlated. There were no other significant associations between an *objective* sleep variable and handedness. In both premenopausal women and >55 -year-old men *subjective* quality of sleep (PSQI) was correlated with direction and degree of handedness (the more right-handed/lateralized the better). In the total sample and postmenopausal women, the degree and direction of handedness were negatively correlated with daytime sleepiness. The chronotype was not associated with handedness in any group.

Conclusion: While associations were not consistent in all groups, overall, right-handedness tended to be associated with better sleep and less daytime sleepiness. Handedness and sleep seemed to be differentially associated in women and men, being in line with endocrine interactions.

Keywords: handedness, sleep, daytime sleepiness, menopause, actigraphy

Introduction

Restorative and sufficient sleep is essential for human well-being.¹ Factors affecting quality and quantity of sleep include sex, age, body mass index (BMI) as well as other health- and lifestyle-related factors.² Another factor probably affecting sleep is handedness.³ Handedness was formerly used as a dichotomous characteristic labelling individuals as either left- or right-handed (LH or RH).⁴ Using this concept, about 90% of the human population are RH.⁵ Research has moved on

to see at least three categories: RH, LH, both termed consistently handed (CH) and inconsistent-handed (ICH).⁶ More modern approaches tend to avoid partitioning altogether and regard handedness as a continuum, which has two qualities: degree, meaning CH vs ICH, as well as direction, meaning RH vs LH.⁷

So far, handedness was inconsistently and in part contradictory reported being associated with several objective and subjective sleep parameters. Overall, lower degrees of lateralization were associated with objectively better sleep including a shorter sleep onset latency (SOL),⁸ a higher sleep efficiency (SE)⁸ and more N-REM sleep.^{8,9} Elsewhere, left-handedness was associated with longer¹⁰ or shorter total sleep time (TST)¹¹ and lower SE.¹¹ In contrast to objective sleep characteristics, lower degrees of lateralization were associated with subjectively impaired sleep, eg a shorter TST¹² or more awakenings.¹³ Similarly, left-handedness was associated with more awakenings⁴ and lower TST.¹⁴ Most studies had limited sample sizes and a small range of ages of the participants, namely college students. Only a single study with solely over 65-year-old participants exists.¹⁵ Moreover, the majority of these studies only used self-report for analyses.^{4,12–14,16} Those using objective measures, ie actigraphy or polysomnography, recorded only a single night or lack of diversity of age or hand preference.^{8–11}

Therefore, rational for our study was to add knowledge on the association between handedness and sleep. Compared to the right-handed majority, altered sleep in non-right-handed individuals could be caused by both, reactively, ie a more stressful life in a world designed for right-handers or a partly differing cortical sleep regulation.

While there is no clear cut lateralization in handedness,¹⁷ which is “simply based on a mirrored organization of hand motor areas”,¹⁸ the extent of activation of brain regions involved in hand movements has been shown to differ between right and left handers.¹⁸ In addition, handedness has been linked to different kinds of brain lateralization, such as language lateralization, eg “more atypical (right hemisphere) lateralization in left handers”.^{19,20}

There is evidence that sex hormones affect lateralization in women (eg during the menstrual cycle^{21,22} and after estrogen replacement therapy²³) as well as in men.^{24,25} In addition, sex hormones also affect sleep in both women^{26,27} and men.²⁸ Therefore, we analyzed the association between handedness and sleep separately for men and women, dividing the cohort into ages for pre- and post-menopause.

Thus, the aim of this study was to examine the association between handedness and objective and subjective sleep, addressing potential age and sex differences in a broad cohort of 1764 participants with ages ranging from 18 to 80 years. While the nature of this study has been exploratory, we expected left-handedness to be associated with impaired sleep and more daytime sleepiness. In addition, we expected different associations in pre- and postmenopausal women.

Materials and Methods

Participants and Experimental Procedure

For this study, we used data from the “LIFE-Adult” study (Leipzig Research Center for Civilization Diseases); for details see.²⁹ “LIFE-Adult” is a population-based study with 10,000 participating adults (age range: predominantly 40 to 79 years, 400 participants with an age range of 18 to 39 years). Participants were randomly recruited from the city of Leipzig, Germany. The LIFE participants took part in a baseline examination, during which various physical examinations (including blood sampling) were carried out, and interviews and questionnaires on various health topics were completed (including sociodemographics, medical history, medication intake). As part of an optional additional examination, a subgroup took part in a 1-week actigraphy examination to record physical activity and sleep behavior. The LIFE study was conducted according to the Declaration of Helsinki and was approved by the ethics committee of the University of Leipzig (registration number: 263-2009-14122009). All participants gave written informed consent.

For the sub-cohort studied here, inclusion criteria comprised actimetry completed for a minimum of 4 out of 5 nights, recording of subjective sleep characteristics using scales and a sleep diary, as well as questionnaires on daytime sleepiness, chronotype and handedness (see below). The following exclusion criteria were defined, potentially affecting sleep: a medical history of stroke, Parkinson’s disease or multiple sclerosis; current diagnosis of depression or cancer or treatment during the previous year. To address undetected depression, the Centre for Epidemiologic Studies – Depression Scale (CES-D) was measured, and participants with a score higher than 22 were excluded.³⁰ Furthermore, precluded were participants using sleeping drugs more than once per week during the preceding month (according to item 7 of

Pittsburgh Sleep Index, PSQI) or taking drugs with sleep-altering effects including hypnotics, tranquilizers, antipsychotics, anxiolytics, opioids and first-generation antihistamines (according to medication anamnesis interview). In addition, in order to minimize the inclusion of participants with otherwise disturbed sleep, only participants who slept more than 4 hours, objectively (according to actigraphy) as well as subjectively (PSQI item 4), were analyzed. In addition, shift workers or participants on parental leave were excluded from analyses.

Sleep was objectively measured using actigraphy (see below) in 2788 participants. Of these, 1024 participants were excluded for not meeting in- or exclusion criteria (see Figure 1). Thus, the resulting study population comprised 1764 persons (908 women and 856 men). Mean (\pm SD) age was 57.8 (\pm 12.2) years, mean BMI was 27.1 (\pm 4.3) kg/m². Women had a mean age of 56.8 (\pm 12.1) years, men had a mean age of 58.8 (\pm 12.2) years. Women had a mean BMI of 26.8 (\pm 4.8) kg/m², men had a mean BMI of 27.5 (\pm 3.7) kg/m². The most diagnosed and reported illnesses were hypertension, elevated blood lipids, thyroid disease, arthrosis, disc prolapse, acid reflux, herpes zoster, 'other skin diseases' (than psoriasis or atopic dermatitis), hay fever and 'other kidney diseases' (than renal insufficiency).

Objective Measurement of Sleep Using Actigraphy

Actigraphy recordings were performed using SenseWear Pro 3 devices (BodyMedia Monitoring System, Bodymedia, Pittsburgh, Pennsylvania, USA). Participants were instructed to wear them for a total of seven consecutive days and nights. During this study period, participants were asked to keep a sleep-log, in which they documented their bedtimes and wake-up times, among other things.

Actigraphy data was analyzed using the SenseWear Professional software package version 6.1 (BodyMedia Monitoring System, Bodymedia, Pittsburgh, Pennsylvania, USA), which scores each recording minute as laying down (yes/no) and sleep (wake vs sleep). The algorithms used are based on multiple sensor parameters (galvanic skin response, skin temperature, 2-axis body acceleration, heat flux) with an off-arm detection in place to note the removal of the device. Validated successfully when compared with PSG, the SenseWear was shown to accurately detect total sleep time, wake after sleep onset and sleep efficiency.^{31–35} Many studies indirectly validated measurements of time in bed, meaning lying duration, by accurately assessing energy expenditure in relation to different activities.^{36–38} Lying duration assessed via this algorithm has been used in studies before.^{39,40} It was also shown that the SenseWear armband performs equally well in comparison with another well-established wearable tool called Actiwatch.^{31,35,41}

Afterwards, data was exported to a Microsoft Excel template with customized Visual Basic for Applications (VBA) macros. The Excel tool was used to customize analysis windows to the specific day-night-cycles of each participant, as no fixed time-window was used for night sleep analyses. Based on the bedtime and wake-up information provided in the sleep log, the respective night sleep episodes were identified manually. Then, the following sleep parameters were calculated for each:

Time in bed (TIB = sum of all minutes classified as lying down)

Total Sleep Time (TST = sum of all minutes classified as sleep)

Sleep onset latency (SOL = sum of all minutes classified as lying down before first time falling asleep)

Sleep efficiency (SE = ratio of TST to TIB)

Number of waking episodes (Nwake = amount of nocturnal waking episodes \geq 5 minutes)

Wake after sleep onset (WASO = sum of all minutes classified as wake between sleep onset and awakening).

For greater reliability, only data from nights during the week was used. Values were averaged across the 5 nights prior to work days (Sunday to Thursday night). Only participants with analyzable data from at least 4 nights were included in the analyses.

Subjective Assessment of Sleep and Sleep Quality

Subjective sleep characteristics and sleep related variables were captured during the baseline visit of the LIFE study using the following self-report questionnaires: The Pittsburgh Sleep Quality Index (PSQI) is a self-rating scale to assess the subjective quality and quantity of sleep during the past four weeks. It consists of 19 individual items, creating 7 components, producing a global score, ranging from 0 to 21 points with higher scores reflecting greater sleep problems.^{42–44} For the analysis of *subjective* sleep, we used items 1 (usual bedtime) and 3 (usual get up time) to

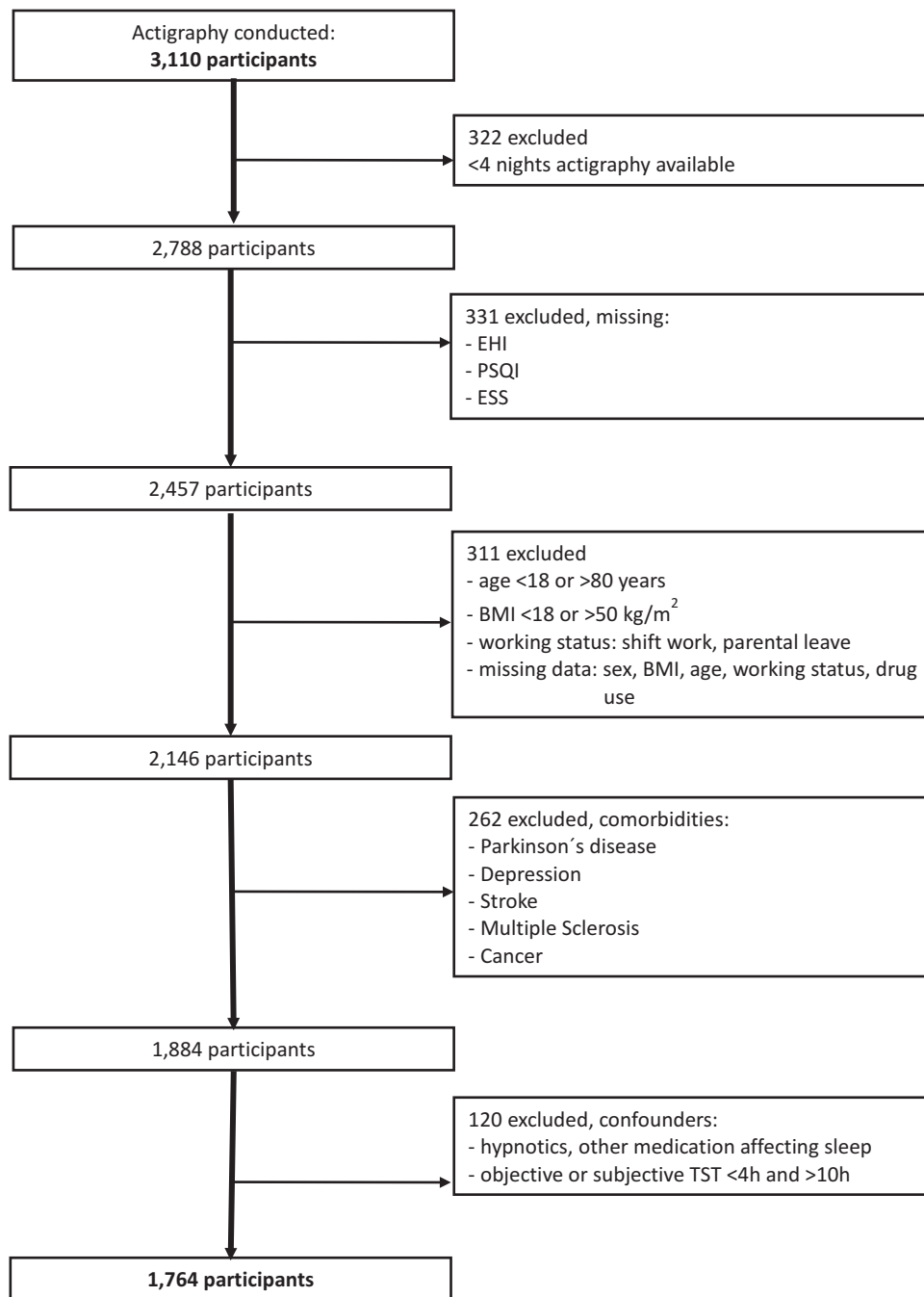


Figure 1 Flowchart illustrating the inclusion and exclusion criteria.

Abbreviations: BMI, body mass index; EHI, Edinburgh Handedness Scale; TST, total sleep time; PSQI, Pittsburgh Sleep Quality Index; ESS, Epworth Sleepiness Scale.

calculate time in bed (TIB_{PSQI}), item 2 (typical sleep onset latency; SOL_{PSQI}) and 4 (usual sleep duration, SD_{PSQI}) and calculated subjective sleep efficiency ($SE_{PSQI} = SD_{PSQI}/TIB_{PSQI}$).

Determination of Daytime Sleepiness and Chronotype

To determine daytime sleepiness, the Epworth Sleepiness Scale (ESS) questionnaire was used. This self-rating instrument assesses the probability of falling asleep in 8 different everyday situations, thus addressing subjective sleepiness and hypersomnias.^{45,46} The ESS ranges from 0 to 24 points, with higher scores reflecting greater daytime sleepiness.

The chronotype was assessed using the German version of the 19-item Morningness-Eveningness-Questionnaire (D-MEQ), identifying individual circadian phase and preferences.^{47,48} The DMEQ ranges from 16 (definitive evening type) to 86 points (definitive morning type).

Determination of Handedness

Handedness was assessed using the Edinburgh Handedness Scale (EHI).⁴⁹ We used the modified German version of the scale comprising questions regarding hand preference in 10 different motor activities (eg writing, throwing, lighting a match) and additionally 10 questions targeting consistency of hand use regarding each of these 10 activities. The EHI score provides real numbers ranging from -100 (CLH, consistently left-handed) to +100 (CRH, consistently right-handed). As we regarded handedness as a continuum, we used metric values of the score for analyses. The EHI-Score (EHI) was used to determine the *direction of handedness*. The absolute value of the EHI-Score (absEHI, range 0 to 100) was used to determine the *degree of handedness*.

Determination of Other Variables

Sex, age, comorbidities, medical history, medication and social economic parameters were assessed via self-report.

Statistical Procedure

Only data recorded during the week was considered for analysis since sleeping patterns on the weekend are less reliant. Then, people engage in different activities, bending their sleeping schedules either to stay up especially late for festivities or to sleep longer to lessen the sleeping debt they may have accumulated during the week.

To control for age and menopausal status, a subgroup-analysis with restricted age ranges was performed. Participants between the ages of 18–45 years were grouped together to constitute a pre-menopausal group, while ≥ 55 year-olds were grouped together to build a post-menopausal group, considering that the mean age of menopause is about 50 years.⁵⁰ The cohort was further stratified for sex, leaving four subgroups: young females (N = 190), young males (N = 137), female seniors (N = 511), and male seniors (N = 519).

Subgroups were compared using *t*-test; if variances were not equal, corrected *t*-values were used. Correlations between sleep parameters and handedness were calculated using Spearman rank correlations. All statistical testing was performed using SPSS Statistics version 24 (IBM Corp., Armonk, New York, USA). *P*-values < 0.05 were considered to be statistically significant. We did not use the Bonferroni correction for multiple testing in this exploratory study aiming at identifying effects worthy of further being studied. Thereby, we minimized the risk of type 2 errors (ie not detecting a true effect) and accepted the risk of type 1 errors (ie detecting a false effect). Type 2 errors are of particular concern in our sample since the absolute number of predominantly left-handed participants is low despite the large sample due to the small proportion. We believe that this approach is in line with both statistical recommendations⁵¹ and current practice.^{52–54}

Results

Objective and Subjective Sleep

Differences between sexes are shown in Table 1. Regarding *objective* sleep, women spent more time in bed (TIB), slept more (TST) and had a higher sleep efficiency (SE) with fewer awakenings (Nwake) and less time awake (WASO). In contrast, women *subjectively* reported to sleep less (shorter SD_{PSQI}), to require more time to fall asleep (longer SOL_{PSQI}) and therefore to sleep less efficiently (lower SE_{PSQI}) than men. Also, their subjective quality of sleep (PSQI score) is worse than in men. However, men score higher regarding daytime sleepiness (ESS score).

Distribution of Handedness

Mean EHI-Scores were 82.41 (SD = 39.45), with most participants (91.0%) being classified as right-handed (RH), according to their EHI-Score. N = 84 (4.8%) participants were classified as left-handed (LH) and N = 74 (4.2%) were classified as ambidextrous. While most RH showed extremely high lateralization (ie EHI-Score = +100), all other individuals were widely spread in their distribution of hand preferences. Strongly lateralized LH (EHI-Score = -100)

Table 1 Handedness, Objective and Subjective Sleep Parameters, Daytime Sleepiness and Chronotype Across the Cohort Separated by Sex

	Female N=908		Male N=856		t	p
	Mean	SD	Mean	SD		
EHI-Score	82.48	40.60	82.32	38.21	-1.889 ^Z	0.059
Absolute EHI score	90.09	18.30	88.59	19.70	-2.037 ^Z	0.042
Objective (actigraphy)						
TIB (h)	7.59	0.93	7.42	0.93	-3.770	<0.001
TST (h)	6.40	0.92	6.11	0.91	-6.610	<0.001
SE (%)	84.43	6.89	82.57	8.05	-5.209	<0.001
SOL (min)	9.91	8.16	9.41	6.73	-1.415	0.157
Nwake	2.71	1.34	2.91	1.51	2.949	0.003
WASO (h)	1.00	0.59	1.09	0.67	2.890	0.004
Subjective (questionnaires)						
TIB _{PSQI} (h)	8.08	1.06	7.97	1.10	-2.103	0.036
SD _{PSQI} (h)	6.76	1.15	6.92	1.06	2.873	0.004
SE _{PSQI} (%)	84.39	13.54	87.47	12.06	5.061	<0.001
SOL _{PSQI} (min)	22.26	23.67	16.54	17.71	-5.761	<0.001
PSQI score	5.40	3.21	4.39	2.54	-7.318	<0.001
ESS score	7.44	3.48	8.27	3.30	5.182	<0.001
D-MEQ score	59.42	8.53	59.72	8.31	0.724	0.469

Notes: Time in decimal values. ^ZZ-Values, Mann-Whitney-U-Test was used. Significant differences are shown in bold.

Abbreviations: TIB, time in bed; TST, total sleep time; SE, sleep efficiency (TST/IB); SOL, sleep onset latency; Nwake, number of awake periods of more than 5 min during night sleep; WASO, time spent awake after sleep onset. Subjective questionnaire-based sleep parameters; TIB, time in bed; SD, sleep duration; SE, sleep efficiency (SD/TIB); SOL, sleep onset latency; EHI, Edinburgh Handedness Scale; PSQI, Pittsburgh Sleep Quality Index; ESS, Epworth Sleepiness Scale; D-MEQ, Morningness-Eveningness-Questionnaire (chronotype).

were very rare with most LH being only mildly lateralized. It is apparent that handedness is a continuum rather than discrete categories.

Degree and direction of handedness for both men and women are depicted in Figure 2. Handedness scores were comparable for women (EHI = 82.48; absEHI = 90.09) and men (EHI = 82.33, absEHI = 88.59), yet the Mann-Whitney-Test reached significance for absEHI ($Z = -2.037$, $p = 0.042$). There were slightly less left-handed men than women (4.1% vs 5.4%), while there were less ambidextrous women than men (3.6% vs 4.8%).

Handedness and Objective Sleep Parameters

In the total sample, time spent awake after sleep onset (WASO) was correlated with handedness. The same was true for the sample of all women (Table 2). In postmenopausal women, in addition to WASO, also time in bed (TIB) and total sleep time (TST) were correlated with handedness. In this subset, right-handedness was associated with longer TIB, longer TST and less WASO (Table 2). Other associations between handedness and objective sleep parameters could not be found. This applies to all other groups looked at: all men, premenopausal women and men stratified for age groups

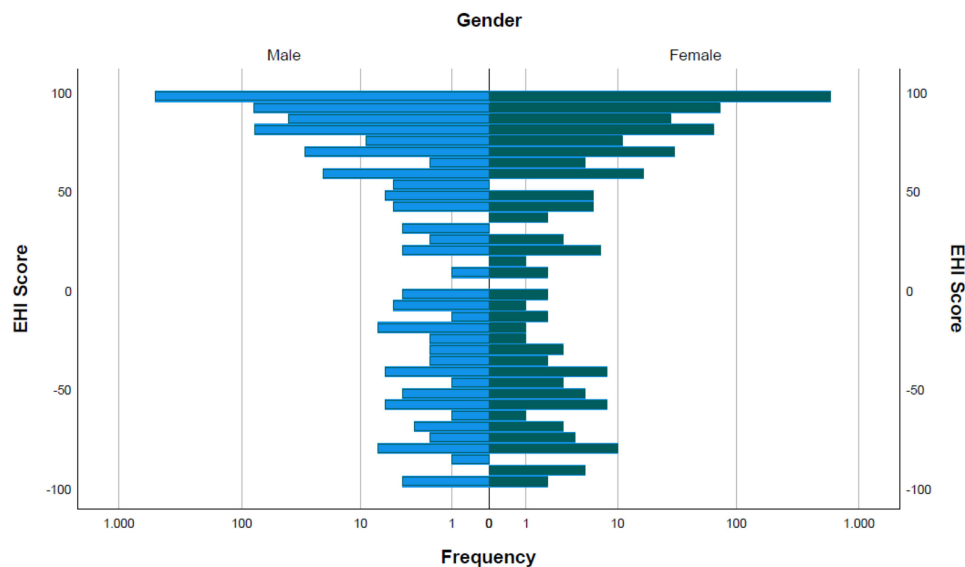


Figure 2 Frequency of the Edinburgh Handedness Scale (EHI)-Score in female and male participants.
Notes: EHI-Score 100 = consistently right-handed. EHI-Score -100 = consistently left-handed.

(Table 2). All significant correlations existed for both EHI and absEHI, meaning that direction and degree of lateralization were correlated with sleep parameters in the same way.

Handedness and Subjective Sleep Parameters

There was no significant association between handedness and a *quantitative* sleep parameter as assessed with the PSQI (eg SOL) in any group. In terms of *quality* of sleep, however, right-handedness was associated with a lower PSQI score in premenopausal women and older men, indicating better sleep quality (Table 3). All significant correlations existed for both EHI and absEHI, meaning that direction and degree of lateralization were correlated with sleep parameters in the same way. In the following groups, neither quantitative nor qualitative PSQI measures were associated with handedness: total group, all women, all men, younger men and postmenopausal women.

Daytime Sleepiness and Chronotype

In the total group and in postmenopausal women, right-handedness was associated with a lower ESS score, ie less daytime sleepiness (Table 3). The chronotype (D-MEQ score) was not associated with handedness in any group.

Discussion

To our knowledge, this is by far the largest study investigating the association between handedness and objective and subjective sleep. Key findings are:

First, the more right-handed/lateralized the participants were, the less they were awake after sleep onset. This was true for the total sample, all women and postmenopausal women. The latter also spent more time in bed and slept more. Secondly, in contrast to these associations with *objective* sleep variables, there was no significant association with any *subjective quantitative* sleep parameter in any group. Thirdly, however, the more right-handed/lateralized premenopausal women and >55-year-old men were, the better their *subjective quality* of sleep was. Fourthly, the more right-handed/lateralized the participants were, the less sleepy they were at daytime. This applied to the total group and postmenopausal women. Thus, overall, while associations were not consistently found in all groups, right-handedness tended to be associated with better sleep and less daytime sleepiness. Overall, associations were weak, though. The finding that direction (EHI) and degree (absEHI) of handedness showed similar correlations is plausible since the vast majority of participants were right-handed and showed a high degree of lateralization.

Table 2 Spearman's Rank Correlation of Direction of Handedness (Mean EHI) and Degree of Handedness (Absolute EHI) with Objective Sleep Parameters Separated by Sex and Age Group

	Total Sample	Female	Male	Female Age 18–45	Female Age ≥ 55	Male Age 18–45	Male Age ≥ 55
N	1764	908	856	190	511	137	519
Mean EHI-Score							
TIB	0.022	0.004	0.034	−0.099	0.087*	0.049	0.014
TST	0.028	0.026	0.021	−0.031	0.096*	−0.029	0.027
SE	0.033	0.053	0.007	0.090	0.065	−0.039	0.017
SOL	0.021	0.005	0.041	0.025	0.007	0.141	0.081
Nwake	−0.025	−0.052	0.007	−0.079	−0.051	0.016	−0.024
WASO	−0.049*	−0.087**	−0.008	−0.101	−0.101*	0.041	−0.048
Absolute EHI-Score							
TIB	0.016	0.002	0.023	−0.090	0.087*	0.048	0.005
TST	0.026	0.027	0.016	−0.015	0.096*	−0.021	0.023
SE	0.035	0.054	0.010	0.097	0.062	−0.029	0.019
SOL	0.022	0.003	0.046	0.018	0.010	0.157	0.074
Nwake	−0.029	−0.053	−0.001	−0.083	−0.047	−0.011	−0.026
WASO	−0.054*	−0.090**	−0.016	−0.110	−0.099*	0.028	−0.050

Notes: *The correlation is significant at the 0.05 level (two-sided); **The correlation is significant at the 0.01 level (two-sided).

Abbreviations: TIB, time in bed; TST, total sleep time; SE, sleep efficiency (TST/IB); SOL, sleep onset latency; Nwake, number of awake periods of more than 5 min during night sleep; WASO, time spent awake after sleep onset.

So far, there are only 11 studies on the association between handedness and sleep. Four of them used objective measuring techniques (actigraphy^{8–11} with one study additionally comparing with polysomnography and self-report¹¹) while seven only used self-reports.^{4,12–16,55}

Studies capturing *objective* sleep variables were rather small (10 to 41 participants) and included only young participants with mean ages ranging from 20.5 to 22.4 years. Results were inconsistent: One study reported right-handedness to be associated with longer total sleep time (TST) and higher sleep efficiency (SE).¹¹ Another study reported left-handedness to be associated with longer sleep duration with no significant differences in sleep onset latency (SOL) or SE.¹⁰ Propper et al reported in a first study, investigating sleep depending on the *degree* of handedness, a higher degree of handedness (ie consistently handed individuals) to be associated with longer SOL and lower SE in women.⁸ In a second study, addressing *direction* of handedness, they compared sleep in 5 consistent LH (4 females) and 5 consistent RH (5 females). Here, the only significant finding is a higher number of REM periods in consistent LH.⁹ Thus overall, no clear picture has arisen from these studies. Our findings also do not show a homogenous picture. Overall, however, direction and degree of handedness (the more right-handed and the more lateralized) were associated with better objective sleep, being roughly in line with the results of one of the studies¹¹ but not of the others.^{8,10}

Research focusing on the association between handedness and *subjective* sleep is limited as well. Except for one¹⁵ out of seven, all studies included young participants with mean ages 16–29 years.^{4,11–14,16} Two studied the degree of handedness,^{13,14} two direction^{4,11} and two both.^{12,16} The one study in elderly (older than 64 years) included 1277 participants but was (regarding sleep) limited to the question “can get enough rest and sleep” in consistent-handed and non-consistent-handed (mixed-handed) participants.¹⁵ A further recent study compared subjective sleep parameters and direction of handedness in 35 gifted and 28 non-gifted children between 8 and 12 years.⁵⁵

Also, in terms of *subjective* sleep, findings were not uniform but less contradictory: Among young adults, a higher *degree* of handedness was found to be associated with longer sleep duration,¹⁴ lower SOL,¹³ less awakenings¹³ and less

Table 3 Spearman's Rank Correlation of Direction of Handedness (Mean EHI) and Degree of Handedness (Absolute EHI) with Subjective Sleep Parameters Separated by Sex and Age Group

	Total Sample	Female	Male	Female Age 18–45	Female Age ≥ 55	Male Age 18–45	Male Age ≥ 55
N	1764	908	856	190	511	137	519
Mean EHI-Score							
TIB _{PSQI}	-0.021	-0.053	0.007	-0.072	-0.011	-0.099	0.003
SD _{PSQI}	-0.012	-0.022	0.004	0.065	-0.011	-0.101	0.023
SE _{PSQI}	0.008	0.029	-0.005	0.070	0.020	-0.006	0.019
SOL _{PSQI}	-0.037	-0.042	-0.044	-0.129	-0.001	-0.077	-0.061
PSQI score	-0.028	-0.035	-0.035	-0.168*	-0.011	0.059	-0.092*
ESS score	-0.049*	-0.055	-0.030	-0.016	-0.094*	0.096	-0.074
D-MEQ score	0.013	0.039	-0.012	-0.033	0.071	-0.080	0.010
Absolute EHI-Score							
TIB _{PSQI}	-0.027	-0.052	-0.007	-0.037	-0.015	-0.120	0.000
SD _{PSQI}	-0.018	-0.027	-0.002	0.079	-0.023	-0.093	0.021
SE _{PSQI}	0.009	0.023	0.004	0.046	0.013	0.028	0.019
SOL _{PSQI}	-0.042	-0.041	-0.057	-0.108	0.004	-0.122	-0.067
PSQI score	-0.029	-0.033	-0.042	-0.156*	-0.005	0.043	-0.096*
ESS score	-0.052*	-0.063	-0.027	-0.045	-0.096*	0.102	-0.069
D-MEQ score	0.009	0.038	-0.021	-0.023	0.072	-0.069	0.012

Note: *The correlation is significant at the 0.05 level (two-sided).

Abbreviations: TIB, time in bed; SD, sleep duration; SE, sleep efficiency (SD/TIB); SOL, sleep onset latency; PSQI, Pittsburgh Sleep Quality Index; ESS, Epworth Sleepiness Scale; D-MEQ, Morningness-Eveningness-Questionnaire (chronotype).

“trouble returning to sleep after an awakening”.¹³ That means overall, a higher degree of handedness tended to be associated with better sleep. A study addressing *direction* of handedness reported right-handedness to be associated with less sleep problems.⁴ Another study, mainly addressing dream recall, found that the sleep duration in left-, right- and mixed-handed individuals was comparable.¹⁶ In elderly participants, the proportion agreeing on the question “can get enough rest and sleep” did not differ between consistent-handed and non-consistent-handed (mixed-handed) participants.¹⁵ Piro et al showed gifted children to be significantly more left-handed, as well as showing a trend towards more sleep disturbances.⁵⁵ Thus, at least in adults, most studies point to better sleep in right-handed or consistent handed participants. These findings are in line with our result of a better sleep quality in pre-menopausal women and older men as assessed with the PSQI total score. Single subjective sleep measures derived from the PSQI (eg TIB) did not show correlations with handedness in our study, though.

Objectively measured TIB and TST were shorter than subjectively reported in our sample (Table 1), being a well-known finding⁵⁶ and a possible reason that associations between handedness and objective and subjective sleep, respectively, were not congruent.

In contrast to sleep, we are not aware of reports on the association of handedness and daytime sleepiness. The less right-handed/consistent handed participants were, the higher the daytime sleepiness was. This interesting finding is in line with the concept that it may be more stressful for left-handers or mixed-handers “to cope in a right-handed world”.¹⁰ Either, sleepiness could be “directly” induced by the higher effort required to manage the daily routine. Or, sleepiness could be caused by impaired night sleep since stress has been shown to impair sleep.^{57–59} In line with that, stress

reduction was repeatedly associated with improved sleep quality.^{60,61} In addition or alternatively to those reactive mechanisms (to higher stress levels), higher sleepiness could also be linked to differences in brain structure or function.

While we did not find striking differences between women and men or between pre- and postmenopausal women, there are several indications that might suggest endocrine influences: For example, TIB and TST were positively correlated in postmenopausal women and negatively in premenopausal women. In the smaller premenopausal group, this did not reach significance, though. Of note, we did not analyze sex hormones so that this assumption ultimately remains speculative.

While handedness appears to be mainly, and sleep partly determined by genetic and epigenetic factors,^{20,62} there is evidence that both lateralization and handedness as well as sleep are also affected by sex hormones. While sex hormones are ‘likely not initially triggering hemispheric asymmetries’, they have ‘been shown to be able to profoundly shape them.’²⁰ For example in premenopausal women, functional cerebral asymmetry (FCA) constantly changes in dependence of their hormonal cycles as shown by the electroencephalogram (EEG)⁶³ or functional magnetic resonance imaging (fMRI).^{21,64} During the follicular phase when estradiol levels are rising, FCA is lowest, and during the menses, lateralization is most pronounced.²¹ Accordingly, the lateralized behavior (figure recognition or spatial attention) changed.^{20,22} In men, salivary testosterone levels in adult men have been linked to cerebral laterality for language.⁶⁵ In addition, testosterone has been shown to affect brain asymmetries in terms of language lateralization⁶⁶ and mental rotation,²⁴ prenatally and during puberty.²⁴ Similarly, androgen exposure in utero has been suggested to influence the development of left-handedness.^{67,68} A recent study found high prenatal testosterone concentrations in amniotic fluids to predict weak hand skill asymmetry scores and high prenatal estradiol to predict predicted weak hand preference in 15-year-old girls, thus overall also suggesting some influence of sex hormones on handedness.⁶⁹ An interplay between sex hormones and handedness in females is also suggested by reports that left-handedness is associated with earlier menopause^{70,71} – yet, here also non-supportive reports exist^{72,73} – and different sex hormone levels in left- and right-handed menopausal women.⁷⁴

Sex hormones also affect human sleep. In women, sleep architecture was found to be dependent on luteinizing hormone (LH), follicle stimulating hormone (FSH), progesterone and estrogen, causing more sleep difficulties during the week before and during menses.⁷⁵ Later in life, reduced sex hormone levels during menopause are associated with sleep difficulties in 40–56% “with 26% experiencing severe symptoms that impact daytime functioning”.⁷⁶ Consistently, progesterone showed sleep-promoting effects in postmenopausal women.^{26,77,78} Furthermore, besides progesterone also estradiol contributes to the regulation of sleep stages.²⁷ In men, low testosterone levels were associated with impaired sleep.^{79,80} While the decreasing sleep efficiency in men during aging has been linked to declining testosterone levels,²⁸ sleep, in turn, plays an important role in endocrine regulation, including maintaining male testosterone levels.^{28,81}

Opposed to a large body of literature reporting non-right handedness to be more common in men, regardless of culture and century,⁸² we did not find a relevant difference in our cohort in terms of direction. This might be due to our comparatively old study cohort: LH have a shorter life expectancy than RH with the earliest deaths in the group of only little lateralized LH.⁸³ In addition, men die younger than women do. Our finding of better *objective* sleep in women but better *subjective* sleep in men is in agreement with current knowledge.⁵⁶

Strengths and Limitations

The main strength of this study is the large sample size comprising both subjective and objective sleep data. By stratifying the cohort according to sex and age, we controlled for the two main confounding factors in sleep regulation.⁸⁴ Additionally, we analyzed the mean values of five consecutive nights in their home environment; thus, the setting was as natural as possible.

It is a limitation that the age distribution was uneven since more participants that are elderly were included. Moreover, it would have been interesting to capture polysomnographic data in order to shed light on sleep stages. It is another limitation that participants with undiagnosed sleep disorders, including obstructive sleep apnea (OSA) and sleep movement disorders, could not be excluded because there were neither data from polysomnography nor from appropriate questionnaires allowing us to do so. Therefore, the study results should be interpreted very carefully. In

terms of insomnia, at least in severe forms, we excluded those with an objective or subjective sleep duration of less than 4 hours.

Conclusions

While associations between sleep parameters and handedness were not consistent in all groups, overall, right-handedness tended to be associated with better sleep and less daytime sleepiness. Handedness and sleep seemed to be differentially associated in women and men, being in line with endocrine interactions.

Abbreviations

EHI, Edinburgh Handedness Inventory (score); absEHI, absolute value of Edinburgh Handedness Inventory score; BMI, body mass index; RH, right-hander; LH, left-hander; CH, consistently handed; ICH, inconsistently handed; CRH, consistently right-handed; CLH, consistently left-handed; TIB, time in bed; SOL, sleep onset latency; TST, total sleep time; SE, sleep efficiency; Nwake, number of times participants woke for more than 5 min during each night; WASO, amount of time spent awake after sleep onset; PSQI, Pittsburgh Sleep Quality Index; D-MEQ, Morningness-Eveningness-Questionnaire, German version; ESS, Epworth Sleepiness Scale.

Ethics Approval and Informed Consent

The study was conducted according to the Declaration of Helsinki and was approved by the ethics committee of the University of Leipzig (registration number: 263-2009-14122009). All participants gave written informed consent.

Data Sharing Statement

Restrictions are applied to the availability of these data. Data was obtained from the Leipzig Research Center for Civilization Diseases. All data and samples of LIFE are the property of the University of Leipzig and are subject to the Law for the Protection of Informal Self-Determination in the Free State of Saxony (Saxon Data Protection Act). Use of data can be requested through the LIFE office (<https://life.uni-leipzig.de/>).

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This work was supported by LIFE – Leipzig Research Center for Civilization Diseases, University of Leipzig. LIFE is funded by means of the European Union, by means of the European Social Fund (ESF), by the European Regional Development Fund (ERDF), and by means of the Free State of Saxony within the framework of the excellence initiative. We acknowledge support from Leipzig University for Open Access Publishing.

Disclosure

All authors declare no conflicts of interest related to this work.

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