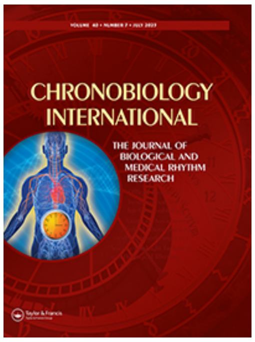

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ORIGINAL ARTICLE

Chronotype and lipid metabolism in Arctic Sojourn Workers

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ABSTRACT

This study relates answers to the Munich Chronotype Questionnaire (MCTQ) and Pittsburgh Sleep Quality Index (PSQI) from Arctic Sojourn Workers (ASW) of Yamburg Settlement, 68° Latitude North, 75° Longitude East ($n = 180$; mean age ± SD; range: 49.2 ± 7.8; 25–66 y; 45% women) to Arctic Sojourn Work Experience (ASWE), age and health status. Chronotype, Mid Sleep on Free Days sleep corrected (MSFsc) and sleep characteristics of ASW were compared to those of age-matched Tyumen Residents (TR, $n = 270$; mean age ± SD; range: 48.4 ± 8.4; 25–69 y; 48% women), 57° Latitude North, 65° Longitude East. ASW have earlier MSFsc than TR (70 min in men, $p < 0.0001$, and 45 min in women, $p < 0.0001$). Unlike TR, their MSFsc was not associated with age ($r = 0.037$; $p = 0.627$) and was linked to a larger Social Jet Lag (+21 min in men; $p = 0.003$, and +18 min in women; $p = 0.003$). These differences were not due to outdoor light exposure (OLE): OLE on work (OLEw) or free (OLEf) days was not significantly different between ASW and TR in men and was significantly less in ASW than in TR women (OLEw: −31 min; $p < 0.001$; OLEf: −24 min; $p = 0.036$). ASWE, but not age, was associated with compromised lipid metabolism in men. After accounting for multiple testing, when corrected for age and sex, higher triglycerides to high-density lipoprotein ratio, TG/HDL correlated with ASWE ($r = 0.271$, $p < 0.05$). In men, greater SJL was associated with lower HDL ($r = -0.204$; $p = 0.043$). Worse proxies of metabolic health were related to unfavorable components of the Pittsburgh Sleep Quality Index in ASW. Higher OLE on free days was associated with lower systolic (b = -0.210; $p < 0.05$) and diastolic (b = -0.240; $p < 0.05$) blood pressure.

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Chronotype; sleep; MCTQ; Arctic; high latitudes; Arctic Sojourn experience; outdoor light; health

Introduction

Natural environmental conditions in the Arctic are associated with numerous challenges to the circadian system, affecting health and well-being (Arendt 2012; Danilenko et al. 2019; Gapon et al. 2006; Gubin et al. 2013; Paul et al. 2015; Unnarsdóttir et al. 2022). The natural photoperiodic environment at higher latitudes varies drastically across seasons, affecting circadian phase and sleep preference. The frequency of late chronotypes commonly increases in higher-latitude residents and corresponds to the lower solar irradiation (Borisenkov et al. 2010, 2012; Hut et al. 2022; Miguel et al. 2014; Leocadio-Miguel et al. 2017). Chronotype is also associated with the amount and timing of light exposure. Longer duration and earlier phase of daily exposure to bright light correlate with morning preference (Refinetti 2019; Shawa et al. 2018). In addition, at higher latitudes, chronotype can be modified by the seasons (Shawa et al. 2018). The response to seasonal and latitudinal features can be very specific, depending on individual differences in endogenous and epigenetic factors that determine light sensitivity (Shawa et al. 2018), with enormous variance among individuals (Phillips et al. 2019).

Working in the Arctic at latitudes above the Polar circle entails month-long sojourns in the Arctic alternating with month-long stays in home cities. Apart from season-related photoperiodic changes, such a working regimen causes additional challenges to the human circadian system due to the recurrent need to adapt and re-adapt to changing environmental conditions. Little is known about adaptive features of Arctic sojourn workers (ASW). Much more knowledge has accumulated concerning the adaptability to shift-work practiced at lower latitudes. Even though rotational Arctic sojourn work is principally different from adaptation to shift-work, both

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regimens may share common features, especially at high latitudes, where re-adaptation to challenges of uncommon ambient light of polar seasons is required. Such adaptability may differ depending on chronotype and/or circadian genotypes. The adaptive capability differs greatly among individuals (Gentry et al. 2021). Some studies assumed that individuals with an evening chronotype may be more flexible in their habitual bedtimes, and more resilient to consequences of night-work. For instance, they may exhibit a higher tolerance for shift work (Boivin et al. 2022; Juda et al. 2013; Kervezee et al. 2021). Other recent studies, however, indicated that evening types may be more susceptible to adverse consequences of shift-work. Actimetry revealed that people with a late chronotype had poorer sleep efficiency and shorter sleep duration when engaged in both night and day shifts (Honkalampi et al. 2022; Martin et al. 2015). On average, late chronotypes have lower conscientiousness compared to morning types (Adan et al. 2012; Hogben et al. 2007). A cross-sectional study investigating urinary 6-sulfatoxymelatonin in 664 men and women concluded that morning-type night shift-workers can better maintain an adequate circadian pattern as compared to evening-type night shift-workers (Bhatti et al. 2014). Moreover, other homeostatic and clock-related genotype features may also be involved. Physiologically based modeling predicted that individuals with similar chronotypes can show very different responses to shift work, depending on intrinsic circadian and homeostatic co-factors (Postnova et al. 2013).

Understanding sleep and circadian preferences of high-latitude workers is needed to properly prevent circadian disruptions using light and/or chronobiotics such as melatonin (Arendt 2012).

Since the knowledge of chronotype in ASW and its relation to age and duration of working experience are currently lacking, this work examines sleep parameters and the distribution of chronotypes, gauged by the Munich Chronotype Questionnaire (MCTQ), in 180 (45% women) ASW (25–66 y of age), with an Arctic Sojourn Work Experience (ASWE) ranging from 1 to 37 y. MCTQ-derived endpoints were compared to age- and gender-matched residents of Tyumen's region.

We also investigated the relationship with age and ASWE of ASW's MCTQ-derived endpoints (chronotype, sleep duration on work days and free days, social jetlag, and outdoor light exposure on work days and free days) and their global score of the Pittsburgh Sleep Quality Index (PSQI) and its components.

To investigate ASWE's impact, we regressed proxies of health (body mass index, blood glucose, lipids, insulin, and blood pressure) as a function of ASWE, also accounting for age since most of these health proxies commonly change with age. In addition, we regressed these proxies of health with MCTQ-derived endpoints and PSQI components.

Materials and methods

This cross-sectional study adhered to the tenets of the Declaration of Helsinki and was approved by the Ethics Committee of Tyumen's Cardiology Research Center, Tomsk's National Research Medical Center, and the Russian Academy of Science (Protocol No. 149, June 3, 2019). Written informed consent was obtained from all participants.

Subjects and data collection

The study on the Arctic Sojourn Workers (ASW) was conducted in Yamburg's settlement, 68° Latitude North, 75° Longitude East during September 1–8, 2020 on 180 voluntary participants aged 25 to 66 y (mean ± SD: 49.2 ± 7.8 y; 45% women). The mean time of sunrise was 4:28 (4:14 → 4:40) and that of sunset was 19:12 (19:27 → 18:57); the Sun's zenith time was 11:50, and the average duration of daylight was 14.75 h (14.28–15.23 h) (15:14→14:17). ASW were engaged in month-long stays in Yamburg alternating with month-long stays in their home cities. One hundred and twenty ASW came from westbound home cities and seven from eastbound cities (both differing by one time zone from Yamburg), while 53 came from within the same time zone as Yamburg. Accordingly, three arrival location categories (ALC) were introduced (Eastbound, Identical, Westbound). All participants were engaged in a monthly ASW regimen: 30 d ASW/30 d at home. None of the participants were engaged in night shift, and none were diagnosed with any sleep disorder. Exclusion criteria were chronic ischemic heart disease, a history of myocardial infarction or acute cerebral circulation disorders, valvular heart disease, atrial fibrillation, and diabetes mellitus. All ASW participants were engaged in activities that do not require hard physical labor or regular outdoor activities (they were office workers, engineers, technicians, or drivers). Controls used for comparison were 270 age- and gender-matched Tyumen Residents (TR) (mean ± SD; range age: 48.4 ± 8.4; 25–69 y; 48% women) who lived in Tyumen city (57° Latitude North, 65° Longitude East). To match TR with ASW, individual data from the available larger TR database were randomly retrieved to meet the following criteria: equal mean age and age range and same sex ratio overall and in two selected age groups (25–44 y and 45–69 y). TR were represented mainly by academic personnel: university professionals, technical staff and administrators. Answers to the MCTQ questionnaire were obtained between April 20 and May 9, 2020. The time of Sunrise was 4:48 (5:13→4:25) and that of Sunset was 20:21 (20:00→20:43); the Sun's zenith time was 12:35, and the average duration of daylight was 15.5 (14.78→16.23) h.

None of the participants in both locations were engaged in shift-work. Most TR participants reported a 5-d work/2-d free weekly schedule, and most ASW participants reported a 6-d work/1-d free weekly schedule. They all completed the Munich ChronoType Questionnaire (MCTQ) (Roenneberg et al. 2003; Wittmann et al. 2006). Since MCTQ is not a scale, its reliability cannot be assessed (Di Milia et al. 2013). The validity of the Russian version of the MCTQ was referred to in numerous previous studies (e.g. Borisenkov et al. 2015; Budkevich et al. 2021; Kolomeichuk et al. 2021). Our recent study also determined that the main MCTQ and PSQI endpoints relate closely to objectively measured variables from actimetry (Borisenkov et al. 2022).

ASW participants also completed the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al. 1989) and provided morning (08–09 a.m.) blood samples to assess biochemical variables as described below. Height (in m) and weight (in kg) were measured in the clinic (height meter R-cm MSK 234, weight meter MIDL MP 200) and used to estimate body mass index ($BMI = weight/height^2$). Office blood pressure (BP) was measured in the morning (08–09 a.m.) in the sitting position by a CS Medica CS 109 Premium (CS Medica, Moscow, Russian Federation) mechanical sphygmomanometer. Office BP was measured according to the existing recommendations (Williams et al. 2018) after 5 min of sitting comfortably in a quiet environment (physician's office). Three consecutive measurements were taken at 2-min intervals and averaged.

Instruments

MCTQ

The MCTQ provided answers to the questions of times of falling asleep and awakening on work days and free days, and of the use of an alarm clock on work days and free days. This information was used to calculate midsleep on free days sleep corrected, MSF_{SC}, social jetlag (SJL), sleep duration on work days (SDw), and sleep duration on free days (SDf), as previously described (Roenneberg et al. 2019). MSFsc (chronotype estimate, cleaned of the confounder sleep debt) was calculated based on SDw/SDf, sleep onset on work days and free days (SOw/SOf), and midsleep on work days or free days (MSw/MSf), as follows: if $SDf \leq SDw$: $MSFsc = MSf = SOf + (SDf/2)$; if $SDf > SDw$: $MSFsc = MSF - ((SDf - SD\mathit{week})/2) = SOf + SD\mathit{week}/2$, where $SD\mathit{week} = (5 \times SDw + 2 \times SDf)/7$ for 5-d work schedule (TR), and $SD\mathit{week} = (6 \times SDw + SDf)/7$, for 6-d work schedule (ASW). MSFsc was calculated after excluding individuals who continued using an alarm clock on free days ($n = 38/27$ in TR/ASW were excluded respectively). Social jet lag was calculated as MSf – MSw. We used the absolute value of SJL ($|MSf - MSw|$) but also discriminated between three subgroups: positive SJL (SJL+): $SJL > 0$; no SJL: $SJL = 0$; and negative SJL (SJL-): $SJL < 0$ in ASW and TR. Outdoor light exposure (OLE): OLE on work (OLEw) or free (OLEf) days were also considered.

Biochemical assessment

In ASW, blood samples were collected using a vacutainer from the ulnar vein, in the morning (8:00–9:00), after a 12-h fast. A biochemical blood test with the determination of the lipid spectrum was carried out on an automatic analyzer (Cobas Integra 400 plus, Switzerland) using analytical kits from "Roche Diagnostics GmbH" (Germany). The levels of total cholesterol (TC), triglycerides (TG), high-density lipoproteins (HDL), low-density lipoproteins (LDL), very low-density lipoproteins (VLDL), apolipoproteins A (ApoA1), and apolipoproteins B (ApoV) were determined in serum by an enzymatic colorimetric method. The Triglyceride-to-HDL Ratio (TG/HDL), an index predicting coronary disease (da Luz et al. 2008), and insulin resistance (Giannini et al. 2011) were calculated. Concentrations of highly sensitive C-reactive protein CRP (hs-CRP) were determined by an immunoturbidimetric method using analytical kits "C-reactive protein hs" from BioSystem (Spain) on a semi-automatic analyzer of the open type "Clima MC-15" (Spain). Homocysteine was determined on the IMMULITE 1000 analyzer (Siemens Diagnostics, USA) by indirect competitive solid-phase chemiluminescent enzyme immunoassay using the analytical kit "Homocystein" (Siemens, USA). C-peptide, insulin, and the precursor of the brain natriuretic peptide (NT-proBNP) were analyzed by the solid – phase chemiluminescent enzyme immunoassay ("sandwich method") on the IMMULITE 2000 analyser (Siemens Healthcare Diagnostics, Germany). All biochemical tests were performed in the certified biochemical laboratory of the Tyumen Cardiology Research Center, Tomsk National Research Medical Center, and Russian Academy of Sciences. The automatic analyser Cobas Integra 400 plus is a widely marketed and validated (Bikila et al. 2022) analyser, as are analytical kits for lipid spectrum from Roche Diagnostics (Otokozawa et al. 2010).

Data analysis

The software packages Excel, STATISTICA 6 and SPSS 23.0 were used for statistical analyses. ANOVA/MANOVA tests of equality of group means were performed. The Shapiro–Wilk's W-test was applied to check for normality of distributions. If variables were distributed normally (W-test's p value > 0.05), a one-way ANOVA was used. Otherwise, the Mann–Whitney, Kruskal–Wallis, and post hoc tests were used. A statistical comparison of correlation strength was performed with the cocor free online software (Diedenhofen and Much 2015). Since both age and ASWE may have an impact on proxies of health, as well as on sleep and chronotype, analysis of covariance and linear regression were applied to assess their relations with MCTQ endpoints (MSFsc; SJL and OLEw/f), PSQI components and global score, and proxies of health. The level of statistical significance was set at 5%. Benjamini-Hochberg's False Discovery Rate correction using an FDR value 0.2 or higher was applied to adjust p values for multiple testing.

Results

Sleep characteristics in Arctic Sojourn Workers vs Tyumen Residents (MCTQ)

Characteristics of the Munich Chronotype Questionnaire Sleep in ASW were compared to age- and gender-matched TR, Table 1. Sleep duration on work days (SDw) in ASW does not differ from TR, irrespective of age, Tables S1 and S2. Sleep duration on free days (SDf), however, was significantly longer in ASW than in TR (35 min on average; 36 min in men, 32 min in women). MCTQ-derived MSFsc was significantly advanced in ASW, by 54 min on average, as compared to TR (Figure 1, Table 1). This difference was evident for both genders (70 min earlier in men and 45 min earlier in women). A similar difference was found after excluding participants who continued using an alarm clock on free days, Table 1. There were fewer alarm users on work days in ASW (64.4%) than in TR (74.2%) ($p = 0.028$), but there was no difference in participants using an alarm on work days who discontinued using an alarm on free days (ASW: 76.7% vs. TR: 80.8%, $p = 0.389$), or continued to use an alarm on free days (ASW: 15.0% vs. TR: 14.2%, $p = 0.821$). Sleep onset and sleep end were earlier in ASW than in TR on work days and free days, irrespective of gender, except for wake time on free days in women, Tables S1 and S2. SJL, which is expected to change with age together with chronotype, is negatively associated with age only in TR ($r = 0.229$; $p = 0.0002$), but shows no association with age in ASW ($r = -0.052$; $p = 0.491$). The difference in correlation strength between TR and ASW reaches borderline significance (Fisher's z = 1.868; $p = 0.062$). There were 12.7% of no SJL (SJL = 0) in TR vs. 14.4% in ASW ($p = 0.662$), and 3.7% negative SJL in TR vs. 1.7% in ASW ($p = 0.199$), but SJL and SJL+ were significantly more frequent in ASW than in TR.

Table 1. MCTQ-derived sleep characteristics in Arctic Sojourn Workers (ASW) and Tyumen Residents (TR).

	YAMBURG (ASW)				TYUMEN (TR)				
	Mean	SD	SE	95% CI	Mean	SD	SE	95% CI	p value
Men									
SDw	7.68	0.88	0.08	7.52; 7.87	7.47	1.18	0.10	7.27; 7.67	0.243
SDf	**9.07**	1.53	0.15	8.77; 9.38	**8.47**	1.42	0.12	8.22; 8.70	**0.006**
SD week	7.82	0.80	0.07	7.65; 7.97	7.73	1.15	0.08	7.55; 7.93	0.217
MSFsc	**2:57**	0:44	0:04	2:48; 3:07	**4:07**	2:16	0:12	3:43; 4:32	**<0.001**
SJL	**1.22**	0.93	0.08	1.02; 1.40	**0.87**	0.77	0.05	0.75; 1.00	**0.003**
SJL+	**1.52**	0.78	0.08	1.33; 1.70	**1.08**	0.70	0.05	0.95; 1.33	**<0.001**
SJL-	−0.50	0.00	0.00	0.50; 0.50	−0.08	0.15	0.07	−0.43; −0.05	0.320
OLEw	2.73	1.57	0.13	1.80; 2.33	2.07	2.68	0.27	2.20; 3.28	0.162
OLEf	3.12	2.45	0.23	2.62; 3.60	3.03	1.85	0.15	2.73; 3.35	0.759
Women									
SDw	7.62	0.75	0.08	7.45; 7.78	7.43	1.80	0.15	7.12; 7.75	0.473
SDf	**8.98**	1.22	0.13	8.72; 9.25	**8.45**	1.27	0.10	8.23; 8.67	**0.011**
SD week	**7.88**	0.72	0.07	7.72; 8.03	**7.62**	1.07	0.08	7.43; 7.82	**0.035**
MSFsc	**2:58**	0:49	0:06	2:46; 3:10	**3:43**	1:18	0:07	3:28; 3:58	**<0.001**
SJL	**1.25**	0.88	0.08	1.05; 1.45	**0.95**	0.87	0.07	0.80; 1.12	**0.011**
SJL+	**1.43**	0.78	0.08	1.25; 1.62	**1.13**	0.80	0.07	0.98; 1.30	**0.006**
SJL-	−0.50	—	—	—; —	−0.37	0.25	0.12	−0.70; −0.03	0.999
OLEw	**1.18**	1.00	0.10	0.97; 1.42	**1.70**	1.08	0.08	1.50; 1.88	<**0.001**
OLEf	**2.23**	1.77	0.18	1.85; 2.63	**2.63**	1.65	0.13	2.35; 2.93	**0.036**

SDw – Sleep Duration on work days; SDf – Sleep Duration on free days; SD week – weekly average sleep duration; MSFsc – midsleep on free days sleep corrected calculated after excluding individuals who used an alarm clock on free days; SJL – Social Jetlag; SJL+: Social Jetlag of individuals with SJL>0; SJL-: Social Jetlag of individuals with SJL<0. OLEw/f – Outdoor Light Exposure for work days and free days. p values: Mann–Whitney U-test. Significant differences and corresponding average values are shown in **bold**. 95% CI – Confidence Interval.

Note that MSFsc and SJL+ show similar differences for men and women, results remaining statistically significant after adjustment of p values for multiple testing at FDR = 0.1.

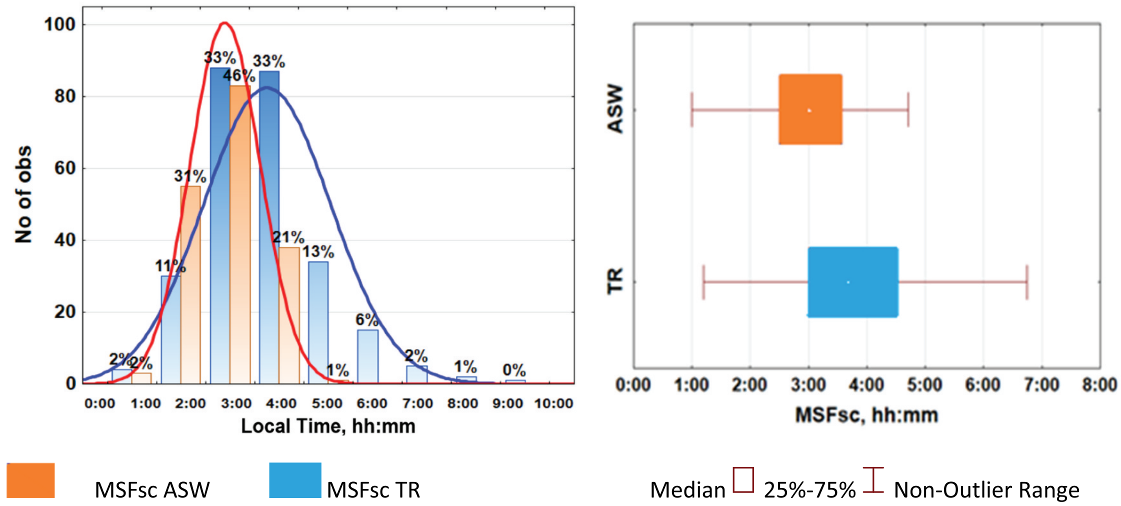

Figure 1. Earlier midsleep on free days sleep corrected (MSFsc) of Arctic Sojourn Workers (ASW) compared to Tyumen Residents (TR). Mann–Whitney Z = 7.703, $p < 0.0001$. Left: MSFsc distribution histogram; right: median MSFsc (dot), interquartile range (colored box) and non-outlier range (line bracket).

OLEw and OLEf did not differ between ASW and TR, but ASW women reported significantly lesser OLEw ($p < 0.001$) and OLEf ($p = 0.036$) than TR women, Table 1. ASW men reported more OLE than ASW women (OLEw: $p < 0.001$; OLEf: $p = 0.014$); TR men showed a similar tendency for OLEw ($p = 0.093$). MSFsc did not differ between ASW whose home city was located west, east, or in the same time zone as Yamburg ($p = 0.6$).

Age-related differences in sleep phase of Arctic Sojourn Workers and Tyumen Residents

The significantly earlier chronotype in ASW compared to TR is evident in the younger age group (25–44 y), Figure 2; overall, MSFsc is not associated with age in ASW (r = 0.016; $p = 0.849$). In TR participants of similar ages, earlier MSFsc correlates significantly with age (r = −0.307, $p < 0.0001$). A correlation comparison (Diedenhofen and Much 2015) shows that these correlations are different (Fisher's z = 2.858, $p = 0.0043$). There were no differences in mean age between alarm users and non-users ($p = 0.852$) in ASW. MANOVA revealed that MSFsc did not depend on age, $p = 0.533$, with no interaction of group*sex, $p = 0.916$ age*sex, $p = 0.925$, or their interaction (age*sex*group), $p = 0.862$. MSFsc and SJL/SJL+ did not depend on ALC in ASW participants, $p =$ 0.864), SJL, $p = 0.937$, or SJL+, $p = 0.507$.

Health proxies, MCTQ, and duration of Arctic Sojourn Work Experience

Several proxies of health were associated with a longer Arctic Sojourn Work Experience (ASWE), Table 2.

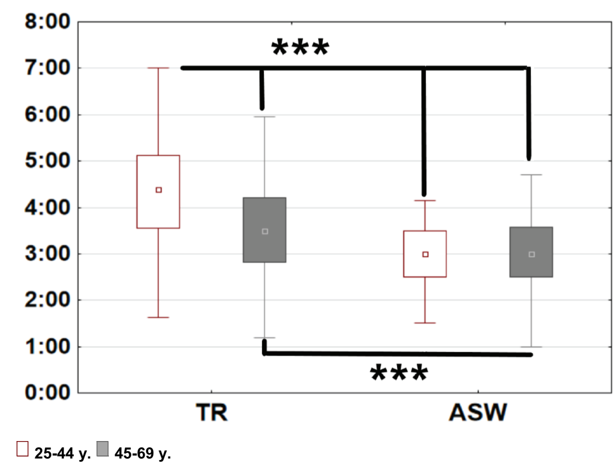

Figure 2. MSFsc (Munich Chronotype Questionnaire-derived midsleep on free days sleep corrected) is earlier in older than in younger Tyumen Residents (TR), but no age difference is observed in Arctic Sojourn Workers (ASW), whose MSFsc is earlier than TR's MSFsc; this difference is already evident in the younger age group of 25–44-year olds. Mann–Whitney U-test; ***$p < 0.0001$.

Relations are found with adverse features in lipid metabolism: higher TG/HDL, which is a marker of cardiovascular risk and insulin resistance ($r = 0.178$, $p =$ 0.018); lower HDL ($r = -0.142$, $p = 0.058$); higher TG ($r = 0.140$, $p = 0.063$); higher VLDL ($r = 0.136$, $p =$ 0.067); and MCTQ-derived shorter sleep duration on weekdays (SDw) ($r = -0.196$, $p = 0.009$). Remarkably, the first eight lowest p values in multivariate regression mode with co-factor of age originated from closely related lipid variables. With Benjamini-Hochberg's FDR 0.2, seven of eight lipid variables have significant association with ASWE when corrected for age, or for

Table 2. Single (Arctic Sojourn Work Experience, ASWE, or age) and multiple (ASWE+age) regression with metabolic proxies of health in the Arctic Sojourn Workers.

	ASWE		Age		ASWE + Age		ASWE + Age + Sex	
Variable	r	*p*	r	*p*	Beta (SD) ± se	*p*	Beta (SD) ± se	*p*
TG/HDL	**0.178**	**0.018**	−0.009	0.903	**0.232 ± 0.084**	**0.006***	*0.222 ± 0.083*	*0.008**
LDL	0.111	0.142	−0.090	0.228	**0.197 ± 0.084**	**0.020**	**0.200 ± 0.085**	**0.019**
HDL	***−0.142***	***0.058***	0.019	0.228	**-0.199 ± 0.085**	**0.020**	**-0.193 ± 0.084**	**0.024**
TG	***0.140***	***0.063***	−0.020	0.795	**0.187 ± 0.085**	**0.029**	*0.178 ± 0.084*	*0.035*
Apo B	0.075	0.318	−0.120	0.105	**0.171 ± 0.084**	**0.044**	**0.178 ± 0.084**	**0.036**
VLDL	***0.136***	***0.067***	−0.006	0.942	**0.174 ± 0.085**	**0.042**	*0.164 ± 0.084*	*0.052*
Total Cholesterol	0.088	0.241	−0.071	0.341	**0.155 ± 0.085**	**0.071**	**0.157 ± 0.085**	**0.067**
Total lipids	0.079	0.295	−0.073	0.332	−0.057 ± 0.086	0.504	−0.053 ± 0.086	0.540
Apo A-1	0.063	0.404	0.064	0.397	0.040 ± 0.086	0.640	0.046 ± 0.086	0.593
C-peptide	−0.068	0.368	−0.066	0.378	−0.048 ± 0.086	0.580	−0.044 ± 0.086	0.609
Insulin	0.070	0.352	0.070	0.352	0.046 ± 0.086	0.594	0.040 ± 0.086	0.638
Blood glucose	0.067	0.373	0.079	0.294	0.036 ± 0.086	0.675	0.039 ± 0.086	0.650
Homocysteine	0.040	0.596	0.015	0.847	0.043 ± 0.086	0.615	0.036 ± 0.085	0.676
NTpro-BNP	0.044	0.563	0.078	0.298	0.019 ± 0.086	0.829	0.027 ± 0.085	0.754
C-reactive protein	0.052	0.494	0.125	0.095	−0.015 ± 0.085	0.864	−0.018 ± 0.085	0.838

TG – Triglycerides; HDL – High-Density Lipoproteins; LDL – Low-Density Lipoproteins; VLDL – Very-Low-Density-Lipoproteins. For simple linear regression: significant associations are in **bold**; borderline significant associations are in ***italic bold***. For multiple regression: significant with Benjamini-Hochberg's False Discovery Rate (FDR) at FDR = 0.2 are in **bold**; *significant at FDR = 0.1. Beta – the average amount by which the dependent variable increases when the independent variable increases one standard deviation and other independent variables are held constant. Variables with significant impact of sex in ASWE + Age + Sex model are in *italic*.

age and sex, Table 2. Three proxies reporting lipid metabolism (TG/HDL, TG, and VLDL) depended on sex and were associated with ASWE mainly in male participants. A strongest lipid correlate (TG/HDL ratio, which was the only variable, which in simple linear regression had a p value <0.05) also was significant in a multiple regression model after correction for multiple testing at FDR = 0.1.

Associations of PSQI and MCTQ with proxies of health in Arctic Sojourn Workers

Linear regression analyses of seven components of PSQI and chronotype (MSFsc) with health proxies such as body mass index, biochemical (blood glucose and lipids) and physiological (blood pressure) variables were performed. There were notable associations between PSQI components and health proxies in the Arctic Sojourn Workers, Table S3. A lower sleep efficiency score (component 4 of PSQI) was associated with a higher C-reactive protein ($r = 0.230$; $p = 0.002$). A higher sleep disturbance score (component 5 of PSQI) was associated with higher insulin ($r = 0.201$; $p = 0.007$), higher BMI ($r = 0.191$; $p = 0.010$), and lower OLE on free days ($r = -0.160$; $p = 0.035$). All these associations were significant with Benjamini-Hochberg's FDR = 0.1. We found no correlation between MSFsc and proxies of health investigated herein. However, in men, greater SJL was associated with lower HDL ($r = -0.204$; $p = 0.043$) that was not observed in women ($r = -0.013$; $p = 0.908$). Interestingly, a longer OLE on free days was associated with lower Systolic Blood Pressure (SBP) and Diastolic Blood Pressure (DBP), Figure 3. These associations were similar in both genders and remained significant after correction for age and sex (SBP, b = −0.210; $p < 0.05$) and DBP (b = −0.240; $p < 0.05$). There was a borderline ($r = -0.136$; $p < 0.08$; age-corrected: b = −0.150; $p < 0.06$) association between a longer OLE on work days and lower blood glucose.

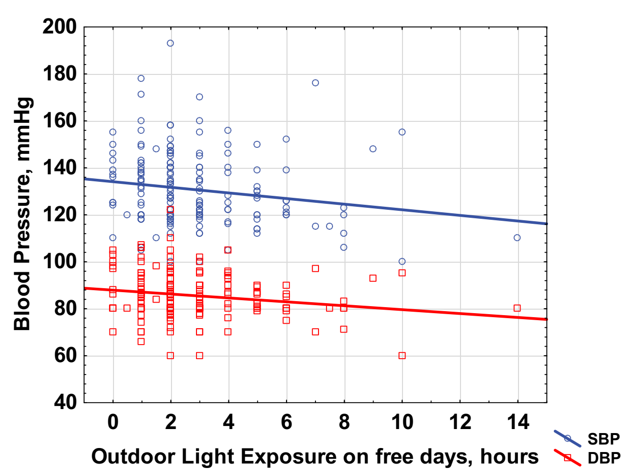

Figure 3. Office blood pressure is associated with outdoor light exposure (OLE) on free days. SBP: systolic blood pressure ($r = -0.167$; $p = 0.028$); DBP: diastolic blood pressure ($r = -0.189$; $p = 0.013$).

Discussion

This study discovered two crucial aspects of circadian preferences in ASW: initial low representation of late chronotypes and absence of an age-dependent trend toward earlier chronotypes. Another important finding relates to compromised health proxies of lipid metabolism and sleep that were associated with ASWE but not with age.

One possible explanation for the earlier chronotype of ASW could be a stricter working regime. Indeed, a 6-d work schedule, longer SDf and greater SJL in ASW may indicate a greater load on their biological clock. However, SJL in both groups was well below 2 h, which is considered a factor of the increased metabolic risks (Al Khatib et al. 2022; Koopman et al. 2017; Rutters et al. 2014). Furthermore, the differences in SD between ASW and TR were evident not only on work days but also on free days and despite the fact that TR consisted predominantly of physicians and teachers who also have a scheduled work regimen. A most important counter-argument is that fewer ASW used an alarm on work days (64.4%) compared to TR (74.2%). As ASW use an alarm clock more rarely despite having an earlier sleep end on work days, such alarm-independence suggests that ASW have an earlier biological clock. Another factor capable of advancing the chronotype could be exposure to ambient daylight, but no differences were found in OLEw or OLEf between ASW and TR, overall and in men. Moreover, in women, OLEw was on average 30 min shorter in ASW than in TR. These observations suggest that the earlier MSFsc of ASW vs. TR could not have been due to a longer exposure to outdoor light. Several alternative explanations can be offered for further testing: 1. A later chronotype may be unfavorable to adapt or resist sojourn work in the Arctic at high latitudes; 2. Working conditions of ASW may cause masking of a late chronotype.

There is a 10° latitude difference between ASW and TR within the same time zone. The fact that ASW are located on average 10° eastward can be another factor contributing to an earlier chronotype, as is a 40-min later sunset time in TR. However, it does not account for the lack of association with age in MSFsc at northern latitudes; furthermore, evening preference is more common at higher latitudes (Borisenkov et al. 2010, 2012; Leocadio-Miguel et al. 2017; Miguel et al. 2014; Randler and Rahafar 2017), since fewer daylight hours correlate with later chronotype. In this study, as well, during the days when MCTQ was performed, daylight hours were on average 45 min shorter for ASW than for TR.

Considering the large individual differences in light sensitivity (Chellappa 2021; Phillips et al. 2019), late chronotypes may face several health issues working under conditions combining work at high Arctic latitudes and the need for regular re-adaptation to the photo-periodic and temperature conditions of the Arctic and conditions back at their home cities. Late chronotypes generally have higher health risks (Knutson and von Schantz 2018; Kobayashi Frisk et al. 2022; Makarem et al. 2020). In another study (Gubin et al. 2015), we documented that evening chronotypes assessed by the Morningness-Eveningness Questionnaire had higher BP and aberrant BP profiles. As such, the much earlier chronotype in ASW may be related to the decimation of late chronotypes (voluntarily or for medical reasons prior to work admission).

Interestingly, the absence in ASW of common associations of MCFsc with age is accompanied by the absence of associations of health proxies with age, while health biomarkers (such as BMI, DBP, glucose, and lipid metabolism) usually change with age. These results could be due to (1) already elevated biomarkers in younger ASW participants or (2) the absence of older participants who would have contributed to such differences.

ASWE was associated with unfavorable health proxies of lipid metabolism, while associations between age and lipid metabolism were absent. It can be hypothesized that the situation could be different should later chronotypes be present in ASW. Of note, later chronotypes can be particularly prone to unfavorable health proxies such as BMI (Sun et al. 2020), glucose (Reutrakul et al. 2013; Zhang et al. 2022), or lipids (Aguilar-Galarza et al. 2021; Zhang et al. 2022). Furthermore, lipids can be altered when circadian light signaling is compromised (Gubin et al. 2022), which is expected while working continuously at high latitudes. The association of SJL with a lower HDL found in ASW men was previously reported for an adult population (Wong et al. 2015). Altogether, the absence of differences in age with minor differences with ASWE may favor the hypothesis that individuals who would have contributed most to a difference in MSFsc with age, i.e. those with a later chronotype, were absent. However, this is still a hypothesis that should be tested in further studies.

Alternatively, results may reflect specifics of adaptation to the particular daily work regimen at higher latitudes. Individual chronometer-related sensitivity to light (Chellappa 2021; Silva et al. 2019; Watson et al. 2018) and psychological factors such as conscientiousness (Adan et al. 2012; Hogben et al. 2007) can cause differences in endurance of different chronotypes to ASW. It was noted that late chronotypes have lower conscientiousness compared to early chronotypes

(Adan et al. 2012; Hogben et al. 2007). Accordingly, fewer dropouts among early chronotypes were noticed during 2 months of the study undertaken during the Polar night (Vitale et al. 2017).

Similar or shared type of work may have influenced circadian behavior as well. For example, shared working regimen among different participants can strengthen circadian rhythms of clock genes by lowering inter-individual variability in circadian phases, even in the environment of the Polar Day (Weissová et al. 2019).

Adaptability to arctic sojourn work may differ among individuals depending on intrinsic clock properties, as it has been shown for adaptability to shift-work. Individual adaptability to shift-work differs greatly among individuals (Gentry et al. 2021). These adaptability differences can be linked to circadian preferences/chronotype. Physiologically based modeling predicted that individuals with a similar chronotype can also provide very different responses to shift work (Postnova et al. 2013). Moreover, sleep duration, timing, and phase of melatonin production at Polar latitudes vary significantly between seasons (Paul et al. 2015). An association between MFSsc and daylight intensity at different geographical locations is not evident (Porcheret et al. 2018).

Recent studies outlined the importance of ambient light and outdoor activities (Blume et al. 2019; Korman et al. 2020, 2022; Weinert and Gubin 2022) for circadian health and chronotype. This work shows an association between time spent outdoors and health benefits such as lower blood pressure and glucose. It was shown that light may influence blood pressure depending on time and mechanisms of action. Daytime blue light exposure decreased blood pressure, possibly by modulating endothelial function and arterial stiffness by release of nitric oxide from photolabile intracutaneous nitric oxide metabolites into the circulation (Stern et al. 2018). Also, light therapy improved diurnal blood pressure control in night shift workers (Hannemann et al. 2021), while nocturnal light increased blood pressure, possibly by suppressing melatonin production (Gubin et al. 2017, 2020). Precise gateways and mechanisms for daylight signaling (skin surface, retina, or both inputs) that can affect vascular tone, cardiac output, and eventually BP are not fully elucidated. Although the correlation between OLE and BP in ASW in our study was modest, it can be physiologically relevant.

Furthermore, we found that greater OLE on work days or free days was associated with a lower sleep disturbance score (component 5 of PSQI). Altogether, these results point to the importance of light hygiene, particularly at high latitudes.

This study also found several associations between poorer sleep as estimated by higher scores of PSQI components and compromised proxies of metabolic health. Similar to MCTQ-derived endpoints, no associations were found between PSQI-derived scores and age or ASWE.

The study has several limitations. The number of participants was modest (180 ASW, 270 TR). The study may have had selection bias as ASW were engaged in the oil and gas industry (mainly engineers, technical workers, drivers), while TR were represented mainly by academic personnel. No details on strictness of work regimen in ASW and TR were obtained, although such information could add important details to the powers of MCTQ. There were no data on biochemical and physiological variables for TR.

As MCTQ and PSQI provide self-reported measures that can have subjective bias, there is a need to obtain similar data by objective measures such as actigraphy. Of note, a recent study revealed a close relationship between non-parametric actimetric indices and main MCTQ and PSQI outcomes (Borisenkov et al. 2022). Although this study showed that ASW workers did not report more outdoor light exposure, additional objective information on the timing of light exposure and on the timing and amount of physical activity could be obtained from actimetry (Weinert and Gubin 2022) in future studies.

Conclusions

The chronotype of ASW did not depend on age, due to lack of late chronotypes in the younger age group already. Proxies of health also did not depend on age in ASW, while they are associated with ASWE. This result likely stems from a combination of different factors, including those, which may be linked to a lack of late chronotypes. Further investigations are needed to verify these observations, preferably based on objective measures such as those available from actimetry.

Author contributions

Conceptualization, D.G., A.V. and D.W.; methodology, D.G., A. V., N.S., L.G., M.B., G.C., and D.W.; software, D.G., A.V., and G. C.; validation, A.V., N.S., and A.G.; formal analysis, A.V., N.S., D.G., D.W., and G.C.; investigation, D.G., A.V., N.S., L.G., B.S., and D.W.; resources, D.G., A.V., N.S., and L.G.; data curation, A. V., N.S., L.G. and D.G.; writing – original draft preparation, D. G.; writing – review and editing, A.V., L.G., D.W., G.C. and M. B.; visualization, D.G., A.V., D.W., and G.C.; supervision, L.G., N.S., A.V. and D.M.; project administration, V.N., T.M. and D. G.; funding acquisition, L.G., A.V., N.S., and D.G. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

Informed consent statement

Written informed consent was obtained from all participants.

Institutional Review board statement

This cross-sectional study adhered to the tenets of the Declaration of Helsinki and was approved by the Ethics Committee of Tyumen Cardiology Research Center, Tomsk National Research Medical Center, Russian Academy of Science (Protocol No. 149, June 3, 2019). Written informed consent was obtained from all participants.

References

Adan A, Archer SN, Hidalgo MP, Di Milia L, Natale V, Randler C. 2012. Circadian typology: a comprehensive review. Chronobiol Int. 29:1153–1175. doi:10.3109/07420528.2012.719971.

Aguilar-Galarza A, García-Gasca T, Mejía C, Díaz-Muñoz M, Pérez-Mendoza M, Anaya-Loyola MA, Garaulet M. 2021. Evening chronotype associates with increased triglyceride levels in young adults in two independent populations. Clin Nutr. 40:2373–2380. doi:10.1016/j.clnu.2020.10.030.

Al Khatib H, Dikariyanto V, Bermingham KM, Gibson R, Hall WL. 2022. Short sleep and social jetlag are associated with higher intakes of non-milk extrinsic sugars, and social jetlag is associated with lower fibre intakes in those with adequate sleep duration: a cross-sectional analysis from the national diet and nutrition survey rolling programme (years 1-9). Public Health Nutr. 25:2570–2581. doi:10.1017/S1368980022000167.

Arendt J. 2012. Biological rhythms during residence in polar regions. Chronobiol Int. 29:379–394. doi:10.3109/07420528.2012.668997.

Bhatti P, Mirick DK, Davis S. 2014. The impact of chronotype on melatonin levels among shift workers. Occup Environ Med. 71:195–200. doi:10.1136/oemed-2013-101730.

Bikila D, Lejisa T, Tolcha Y, Bashea C, Meles M, Getahun T, Ashebir G, Habtu W, Challa F. 2022. Comparison of selected clinical chemistry assay results by two analyzers: Cobas 6000 (c501) and Cobas integra 400 plus. Clin Lab. 68. doi:10.7754/Clin.Lab.2021.210734.

Blume C, Garbazza C, Spitschan M. 2019. Effects of light on human circadian rhythms, sleep and mood. Somnologie (Berl). 23:147–156. doi:10.1007/s11818-019-00215-x.

Boivin DB, Boudreau P, Kosmadopoulos A. 2022. Disturbance of the circadian system in shift work and its health impact. J Biol Rhythms. 37:3–28. doi:10.1177/07487304211064218.

Borisenkov MF, Kosova AL, Kasyanova ON. 2012. Impact of perinatal photoperiod on the chronotype of 11- to 18-year-olds in northern European Russia. Chronobiol Int. 29:305–310. doi:10.3109/07420528.2011.653612.

Borisenkov MF, Perminova EV, Kosova AL. 2010. Chronotype, sleep length, and school achievement of 11- to 23-year-old students in northern European Russia. Chronobiol Int. 27:1259–1270. doi:10.3109/07420528.2010.487624.

Borisenkov MF, Petrova NB, Timonin VD, Fradkova LI, Kolomeichuk SN, Kosova AL, Kasyanova ON. 2015. Sleep characteristics, chronotype and winter depression in 10-20-year-olds in northern European Russia. J Sleep Res. 24:288–295. doi:10.1111/jsr.12266.

Borisenkov M, Tserne T, Bakutova L, Gubin D. 2022. Actimetry-derived 24 h rest–activity Rhythm indices applied to predict MCTQ and PSQI. Appl Sci. 12:6888. doi:10.3390/app12146888.

Budkevich RO, Putilov AA, Tinkova EL, Budkevich EV. 2021. Chronobiological traits predict the restrained, uncontrolled, and emotional eating behaviors of female university students. Chronobiol Int. 38:1032–1041. doi:10.1080/07420528.2021.1903483.

Buysse DJ, Reynolds CF 3rd, Monk TH, Berman SR, Kupfer DJ. 1989. The Pittsburgh sleep quality index: a new instrument for psychiatric practice and research. Psychiatry Res. 28:193–213. doi:10.1016/0165-1781(89)90047-4.

Chellappa SL. 2021. Individual differences in light sensitivity affect sleep and circadian rhythms. Sleep. 44:zsaa214. doi:10.1093/sleep/zsaa214.

da Luz PL, Favarato D, Faria-Neto JR Jr, Lemos P, Chagas AC. 2008. High ratio of triglycerides to HDL-cholesterol predicts extensive coronary disease. Clinics (Sao Paulo). 63:427–432. doi:10.1590/S1807-59322008000400003.

Danilenko KV, Kobelev E, Semenova EA, Aftanas LI. 2019. Summer-winter difference in 24-h melatonin rhythms in subjects on a 5-workdays schedule in Siberia without daylight saving time transitions. Physiol Beh. 212:112686. doi:10.1016/j.physbeh.2019.112686.

Diedenhofen B, Much J. 2015. Cocor: a comprehensive solution for the statistical comparison of correlations. PloS One. 10:e0121945. doi:10.1371/journal.pone.0121945.

Di Milia L, Adan A, Natale V, Randler C. 2013. Reviewing the psychometric properties of contemporary circadian typology measures. Chronobiol Int. 30:1261–1271. doi:10.3109/07420528.2013.817415.

Gapon LI, Shurkevich NP, Vetoshkin AS, Gubin DG. 2006. The rhythms of arterial pressure and heart rate in individuals with arterial hypertension under the conditions of far North. Klin Med (Mosk). 84:39–44.

Gentry NW, Ashbrook LH, Fu YH, Ptáček LJ. 2021 16. Human circadian variations. J Clin Invest. 131:e148282. doi:10.1172/JCI148282.

Giannini C, Santoro N, Caprio S, Kim G, Lartaud D, Shaw M, Pierpont B, Weiss R. 2011. The triglyceride-to-HDL cholesterol ratio: Association with insulin resistance in obese youths of different ethnic backgrounds. Diabetes Care. 34:1869–1874. doi:10.2337/dc10-2234.

Gubin D, Cornelissen G, Weinert D, Vetoshkin AS, Gapon LI, Shurkevich NP, Poshinov FA, Belozerova NV, Danilova LA. 2013. Circadian disruption and vascular variability disorders (VVD) — mechanisms linking aging, disease state and Arctic shift-work: applications for chronotherapy. World Heart J. 5:285–306.

Gubin D, Neroev V, Malishevskaya T, Kolomeichuk S, Weinert D, Yuzhakova N, Nelaeva A, Filippova Y, Cornelissen G. 2022. Daytime lipid metabolism modulated by CLOCK gene is linked to retinal ganglion cells damage in Glaucoma. Appl Sci. 12:6374. doi:10.3390/app12136374.

Gubin DG, Vetoshkin AS, Bolotnova TV, Danilova LA, Poshinov FA, Durov AM, Solovieva SV, Vasilkova TN, Ushakov PA. 2015. Arctic shift-workers' blood pressure and heart rate circadian rhythms and variability depending on morningness/eveningness chronotype score. Meditsinskaya Nauka I Obrazonaie Urala. 82:108–111. eLIBRARY ID: 23695175.

Gubin D, Weinert D, Rybina SV, Danilova LA, Solovieva SV, Durov AM, Prokopiev NY, Ushakov PA. 2017. Activity, sleep and ambient light have a different impact on circadian blood pressure, heart rate and body temperature rhythms. Chronobiol Int. 34:632–649. doi:10.1080/07420528.2017.1288632.

Gubin D, Weinert D, Solovieva SV, Durov AM, Litvinova NS, Danilova LA, Prokopiev NY, Trushnikov DY, Kartashova EA. 2020. Melatonin attenuates light-at-night effects on systolic blood pressure and body temperature but does not affect diastolic blood pressure and heart rate circadian rhythms. Biol Rhythm Res. 51:780–793. doi:10.1080/09291016.2018.1564586.

Hannemann J, Laing A, Middleton B, Cridland J, Staels B, Marx N, Grant PJ, Federici M, Stenberg T, Skene DJ et al, 2021. Light therapy improves diurnal blood pressure control in night shift workers via reduction of catecholamines: the EuRhythDia study. J Hypertens. 39:1678–1688. doi:10.1097/HJH.0000000000002848.

Hogben AL, Ellis J, Archer SN, von Schantz M. 2007. Conscientiousness is a predictor of diurnal preference. Chronobiol Int. 24:1249–1254. doi:10.1080/07420520701791596.

Honkalampi K, Kupari S, Järvelin-Pasanen S, Saaranen T, Vauhkonen A, Räsänen K, Härmä M, Lindholm H, Perkiö-Mäkelä M, Tarvainen MP, et al. 2022. The association between chronotype and sleep quality among female home care workers performing shift work. Chronobiol Int. 39:747–756. doi:10.1080/07420528.2022.2033256.

Hut RA, Paolucci S, Dor R, Kyriacou CP, Daan S. 2022. Latitudinal clines: an evolutionary view on biological rhythms. Proc R Soc B. 280:20130433. doi:10.1098/rspb.2013.0433.

Juda M, Vetter C, Roenneberg T. 2013. Chronotype modulates sleep duration, sleep quality, and social jet lag in shift-workers. J Biol Rhythms. 28:141–151. doi:10.1177/0748730412475042.

Kervezee L, Gonzales-Aste F, Boudreau P, Boivin DB. 2021. The relationship between chronotype and sleep behavior during rotating shift work: a field study. Sleep. 44:zsaa225. doi:10.1093/sleep/zsaa225.

Knutson KL, von Schantz M. 2018. Associations between chronotype, morbidity and mortality in the UK biobank cohort. Chronobiol Int. 35:1045–1053. doi:10.1080/07420528.2018.1454458.

Kobayashi Frisk M, Hedner J, Grote L, Ekblom Ö, Arvidsson D, Bergström G, Börjesson M, Zou D. 2022. Eveningness is associated with sedentary behavior and increased 10-year risk of cardiovascular disease: the SCAPIS pilot cohort. Sci Rep. 12:8203. doi:10.1038/s41598-022-12267-5.

Kolomeichuk SN, Randler C, Morozov AV, Gubin DG, Drake CL. 2021. Social jetlag and excessive daytime sleepiness from a sample of Russian children and adolescents. Nat Sci Sleep. 13:729–737. doi:10.2147/NSS.S290895.

Koopman ADM, Rauh SP, van 't Riet E, Groeneveld L, van der Heijden AA, Elders PJ, Dekker JM, Nijpels G, Beulens JW, Rutters F. 2017. The association between social jetlag, the metabolic syndrome, and type 2 diabetes mellitus in the general population: the new Hoorn study. J Biol Rhythm. 32:359–368. doi:10.1177/0748730417713572.

Korman M, Tkachev V, Reis C, Komada Y, Kitamura S, Gubin D, Kumar V, Roenneberg T. 2020. COVID-19-mandated social restrictions unveil the impact of social time pressure on sleep and body clock. Sci Rep. 10:22225. doi:10.1038/s41598-020-79299-7.

Korman M, Tkachev V, Reis C, Komada Y, Kitamura S, Gubin D, Kumar V, Roenneberg T. 2022. Outdoor daylight exposure and longer sleep promote wellbeing under COVID-19 mandated restrictions. J Sleep Res. 31:e13471. doi:10.1111/jsr.13471.

Leocadio-Miguel MA, Louzada FM, Duarte LL, Areas RP, Alam M, Freire MV, Fontenele-Araujo J, Menna-Barreto L, Pedrazzoli M. 2017. Latitudinal cline of chronotype. Sci Rep. 7:5437. doi:10.1038/s41598-017-05797-w.

Makarem N, Paul J, Giardina EV, Liao M, Aggarwal B. 2020. Evening chronotype is associated with poor cardiovascular health and adverse health behaviors in a diverse population of women. Chronobiol Int. 37:673–685. doi:10.1080/07420528.2020.1732403.

Martin JS, Laberge L, Sasseville A, Bérubé M, Alain S, Houle J, Hébert M. 2015. Day and night shift schedules are associated with lower sleep quality in evening-types. Chronobiol Int. 32:627–636. doi:10.3109/07420528.2015.1033425.

Miguel M, Oliveira VC, Pereira D, Pedrazzoli M. 2014. Detecting chronotype differences associated to latitude: A comparison between Horne–Östberg and Munich chronotype questionnaires. Ann Hum Biol. 41:105–108. doi:10.3109/03014460.2013.832795.

Otokozawa S, Ai M, Asztalos BF, White CC, Demissie-Banjaw S, Cupples LA, Nakajima K, Wilson PW, Schaefer EJ. 2010. Direct assessment of plasma low density lipoprotein and high density lipoprotein cholesterol levels and coronary heart disease: results from the Framingham offspring study. Atherosclerosis. 213:251–255. doi:10.1016/j.atherosclerosis.2010.02.041.

Paul MA, Love RJ, Hawton A, Brett K, McCreary DR, Arendt J. 2015. Sleep deficits in the high Arctic summer in relation to light exposure and behaviour: use of melatonin as a countermeasure. Sleep Med. 16:406–413. doi:10.1016/j.sleep.2014.12.012.

Phillips AJK, Vidafar P, Burns AC, McGlashan EM, Anderson C, Rajaratnam SMW, Lockley SW, Cain SW. 2019. High sensitivity and interindividual variability in the response of the human circadian system to evening light. Proc Natl Acad Sci U S A. 116:12019–12024. doi:10.1073/pnas.1901824116.

Porcheret K, Wald L, Fritschi L, Gerkema M, Gordijn M, Merrrow M, Rajaratnam SMW, Rock D, Sletten TL, Warman G, et al. 2018. Chronotype and environmental light exposure in a student population. Chronobiol Int. 35:1365–1374. doi:10.1080/07420528.2018.1482556.

Postnova S, Robinson PA, Postnov DD, Cymbalyuk G. 2013. Adaptation to shift work: physiologically based modeling of the effects of lighting and shifts' start time. PloS One. 8: e53379. doi:10.1371/journal.pone.0053379.

Randler C, Rahafar A. 2017. Latitude affects morningness-eveningness: evidence for the environment hypothesis based on a systematic review. Sci Rep. 7:39976. doi:10.1038/srep39976.

Refinetti R. 2019. Chronotype variability and patterns of light exposure of a large cohort of United States residents. Yale J Biol Med. 92:179–186.

Reutrakul S, Hood MM, Crowley SJ, Morgan MK, Teodori M, Knutson KL, Van Cauter E. 2013. Chronotype is independently associated with glycemic control in type 2 diabetes. Diabetes Care. 36:2523–2529. doi:10.2337/dc12-2697.

Roenneberg T, Pilz LK, Zerbini G, Winnebeck EC. 2019. Chronotype and social jetlag: a (self-) critical review. Biology (Basel). 8:54. doi:10.3390/biology8030054.

Roenneberg T, Wirz-Justice A, Merrow M. 2003. Life between clocks: daily temporal patterns of human chronotypes. J Biol Rhythm. 18:80–90. doi:10.1177/0748730402239679.

Rutters F, Lemmens SG, Adam TC, Bremmer MA, Elders PJ, Nijpels G, Dekker JM. 2014. Is social jetlag associated with an adverse endocrine, behavioral, and cardiovascular risk profile? J Biol Rhythm. 29:377–383. doi:10.1177/0748730414550199.

Shawa N, Rae DE, Roden LC. 2018. Impact of seasons on an individual's chronotype: current perspectives. Nat Sci Sleep. 10:345–354. doi:10.2147/NSS.S158596.

Silva A, Simón D, Pannunzio B, Casaravilla C, Díaz Á, Tassino B. 2019. Chronotype-dependent changes in sleep habits associated with dim light melatonin onset in the Antarctic summer. Clocks Sleep. 1:352–366. doi:10.3390/clockssleep1030029.

Stern M, Broja M, Sansone R, Gröne M, Skene SS, Liebmann J, Suschek CV, Born M, Kelm M, Heiss C. 2018. Blue light exposure decreases systolic blood pressure, arterial stiffness, and improves endothelial function in humans. Eur J Prev Cardiol. 25:1875–1883. doi:10.1177/2047487318800072.

Sun X, Gustat J, Bertisch SM, Redline S, Bazzano L. 2020. The association between sleep chronotype and obesity among black and white participants of the Bogalusa heart study. Chronobiol Int. 37:123–134. doi:10.1080/07420528.2019.1689398.

Unnarsdóttir AB, Hauksdóttir A, Aspelund T, Gunnarsdóttir V, Tómasson G, Jakobsdóttir J, Anna Valdimarsdóttir U, Thordardottir EB. 2022. Sleep disturbances among women in a subarctic region: a nationwide study. Sleep. 45:zsac100. doi:10.1093/sleep/zsac100.

Vitale JA, Bjoerkesett E, Campana A, Panizza G, Weydahl A. 2017. Chronotype and response to training during the polar night: a pilot study. Int J Circumpolar Health. 76:1320919. doi:10.1080/22423982.2017.1320919.

Watson LA, Phillips AJK, Hosken IT, McGlashan EM, Anderson C, Lack LC, Lockley SW, Rajaratnam SMW, Cain SW. 2018. Increased sensitivity of the circadian system to light in delayed sleep-wake phase disorder. J Physiol. 596:6249–6261. doi:10.1113/JP275917.

Weinert D, Gubin D. 2022. The impact of physical activity on the circadian system: benefits for health, performance and wellbeing. Appl Sci. 12:9220. doi:10.3390/app12189220.

Weissová K, Škrabalová J, Skálová K, Bendová Z, Kopřivová J. 2019. The effect of a common daily schedule on human circadian rhythms during the Polar Day in Svalbard: a field study. J Circadian Rhythms. 17:9. doi:10.5334/jcr.186.

Williams B, Mancia G, Spiering W, Agabiti Rosei E, Azizi M, Burnier M, Clement DL, Coca A, de Simone G, Dominiczak A et al, 2018. Authors/Task force members: . 2018 ESC/ESH guidelines for the management of arterial hypertension: the task force for the management of arterial hypertension of the European society of cardiology and the European society of hypertension. J Hypertens. 36:1953–2041. doi:10.1097/HJH.0000000000001940.

Wittmann M, Dinich J, Merrow M, Roenneberg T. 2006. Social jetlag: misalignment of biological and social time. Chronobiol Int. 23:497–509. doi:10.1080/07420520500545979.

Wong PM, Hasler BP, Kamarck TW, Muldoon MF, Manuck SB. 2015. Social jetlag, chronotype, and cardiometabolic risk. J Clin Endocrinol Metab. 100:4612–4620. doi:10.1210/jc.2015-2923.

Zhang R, Cai X, Lin C, Yang W, Lv F, Wu J, Ji L. 2022. The association between metabolic parameters and evening chronotype and social jetlag in non-shift workers: a meta-analysis. Front Endocrinol (Lausanne). 13:1008820. doi:10.3389/fendo.2022.1008820.