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SOCIAL JETLAG: MISALIGNMENT OF BIOLOGICAL AND SOCIAL TIME

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Humans show large differences in the preferred timing of their sleep and activity. This so-called "chronotype" is largely regulated by the circadian clock. Both genetic variations in clock genes and environmental influences contribute to the distribution of chronotypes in a given population, ranging from extreme early types to extreme late types with the majority falling between these extremes. Social (*e.g.*, school and work) schedules interfere considerably with individual sleep preferences in the majority of the population. Late chronotypes show the largest differences in sleep timing between work and free days leading to a considerable sleep debt on work days, for which they compensate on free days. The discrepancy between work and free days, between social and biological time, can be described as 'social jetlag.' Here, we explore how sleep quality and psychological wellbeing are associated with individual chronotype and/or social jetlag. A total of 501 volunteers filled out the Munich ChronoType Questionnaire (MCTQ) as well as additional questionnaires on: (i) sleep quality (SF-A), (ii) current psychological wellbeing (Basler Befindlichkeits-bogen), (iii) retrospective psychological wellbeing over the past week (POMS), and (iv) consumption of stimulants (*e.g.*, caffeine, nicotine, and alcohol). Associations of chronotype, wellbeing, and stimulant consumption are strongest in teenagers and young adults up to age 25 yrs. The most striking correlation exists between chronotype and smoking, which is significantly higher in late chronotypes of all ages (except for those in retirement). We show these correlations are most probably a consequence of social jetlag, *i.e.*, the discrepancies between social and biological timing rather than a simple association to different chronotypes. Our results strongly suggest that work (and school) schedules should be adapted to chronotype whenever possible.

Keywords Chronotype, Morningness-eveningness, Psychological wellbeing, Sleep quality, Smoking habits

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INTRODUCTION

Daily rhythms in fundamental aspects of physiology and behavior are controlled by an endogenous biological clock. They persist in temporal isolation experiments with a period of approximately 24 h (hence circadian, about 1 day) and have been shown for many biological functions, ranging from the sleep/wake cycle and physiology, *e.g.*, temperature, melatonin, and cortisol (Bailey and Heitkemper, 1991, 2001; Duffy et al., 2001; Waterhouse et al., 2001) to gene expression (Clayton et al., 2001; Young and Kay, 2001).

Circadian clocks are synchronized (entrained) by environmental signals (zeitgebers), predominantly by light (Roenneberg et al., 2003a). Individual differences in entrainment characteristics are well described in animals (Aschoff and Pohl, 1978) and in humans (Horne and Östberg, 1977), yielding a continuum of so-called "chronotypes". In a given population, chronotypes range from early to late types—the colloquial "larks" and "owls" (Natale et al., 2002; Roenneberg et al., 2003b). Larks spontaneously wake up at an early hour and find it difficult to stay up late in the evening, while extreme owls are almost nocturnal in their activity, going to bed in the early morning hours and sleeping late into the day.

Normal work schedules—typically starting early in the day—are best suited for the preferred sleep/wake times of early chronotypes; yet, late chronotypes (moderate to extreme) represent the majority of the population. Late sleep onsets (controlled by the endogenous clock) combined with early arousals (controlled by the external, social clock) lead late chronotypes to accumulate a substantial sleep debt during the work week, for which they compensate on weekends by extending sleep duration (Giannotti et al., 2002; Roenneberg et al., 2003b; Taillard et al., 2003). Late chronotypes more frequently report lower sleep quality and daytime tiredness than do early chronotypes (Giannotti et al., 2002; Taillard et al., 2003; Volk et al., 1994). Several studies have shown relationships between chronotype and psychological wellbeing; for example, late types report psychological and psychosomatic disturbances more often than do early types (Giannotti et al., 2002; Mecacci and Rocchetti, 1998).

Adolescents tend to be much later chronotypes than other age groups (Carskadon et al., 1999, 2001; Roenneberg et al., 2004), and depressed mood shows a high incidence in students who are particularly late chronotypes (Chelminski et al., 1999; Giannotti et al., 2002; Takeuchi et al., 2002). In addition, late chronotypes consume more stimulants (alcohol and coffee) and are more often habitual smokers than are early chronotypes (Adan, 1994; Mecacci and Rocchetti, 1998; Taillard, 1999). Alcohol and nicotine consumption are considered as behavioral symptoms of the inability to cope with social demands (Steinhausen and Metzke, 1998). These findings led to the hypothesis that late chronotypes experience affective disturbances because their endogenous sleep/wake rhythms rarely fit conventional social schedules.

Most chronotype studies use questionnaires that focus on highly subjective ratings of preferred sleep and activity times, *e.g.*, "At what time would you get up if you were entirely free to plan your day" (Horne and Östberg, 1976) or on hypothetical situations, *e.g.*, "If you always had to rise at 6:00, what do you think it would be like?" (Torsvall and Akerstedt, 1980), while actual sleep and activity times are rarely queried. To quantitatively assess the timing of sleep and wakefulness, the Munich ChronoType Questionnaire, (MCTQ) (Roenneberg et al., 2003b) uses simple questions about sleep times, separately addressing free and work days. The MCTQ and the morningness-eveningness questionnaire have been validated against each other and show excellent correlations (Zavada et al., 2005). With this new questionnaire, we re-investigated the associations between chronotype, quality of sleep, psychological wellbeing, and stimulant consumption. Most prior studies investigating these relationships focused on adolescents and students (Chelminski et al., 1999; Giannotti et al., 2002; Takeuchi et al., 2002, 2005). Our study includes subjects ranging from teenagers to the elderly. We describe an interaction between biological and societal clocks that can lead to a chronic form of jetlag, depending on chronotype and social situation ('social jetlag'). Previously, jetlag only referred to side-effects (Waterhouse et al., 2003, 2005) of the relatively infrequent travel by people across time zones, but the impact of 'social jetlag' on physiology is a major feature of modern life with far-reaching implications which has, so far, been largely overlooked.

SUBJECTS AND METHODS

Our study is based on 501 subjects (198 men and 303 women aged 14 to 94 yrs). Participants were recruited by various methods (a database of volunteers having previously participated in studies, flyers posted in public places, and word of mouth). We selected only non-institutional participants who live at home without a medical history of neurological or psychiatric disorders. Data were collected between late spring and early autumn (May and September 2002). Subjects in our sample population had various levels of education: 24 had not yet finished their education, 103 graduated from primary school (*Hauptschule*, on average at 15 yrs of age), 111 from secondary school (*Realschule*, on average at 16 yrs of age), 120 from high school (*Gymnasium*, on average at 19 yrs of age) without further education, and 141 subjects had a university/college degree. The study was conducted in accord with the standards established by the Journal for human biological rhythm research (Touitou et al., 2004).

All subjects filled out the MCTQ (Roenneberg et al., 2003b) as well as additional questionnaires (see below). To estimate chronotype by a single phase reference point, the midpoint between sleep onset and waking on free days (mid-sleep on free days, MSF) was calculated based on the MCTQ. Although MSF is a good indicator of chronotype, sleep deprivation during the work week can act as a confounder for the sleep duration on free days (sleep compensation), leading to a later MSF (Roenneberg et al., 2003b). We corrected for these excessive free-day sleep times, based on the individual (weekly) average sleep need (for correction algorithm, see supplement to Roenneberg et al., 2004). The resulting, sleep-corrected mid-sleep on free days (MSFsc) is an excellent predictor for chronotype; like for MSF, the dimension of MSFsc is not a score but a representation of local time.

Sleep quality was assessed by the SF-A questionnaire (Goertelmeyer, 1985). 23 questions address events and psychological wellbeing the prior evening, the quality of sleep during the past night, and psychological wellbeing on the present morning. Fifteen of these can be grouped into the 5 subscales: (1) sleep quality, (2) sleep-related recovery, (3) feeling of mental balance in the evening, (4) feeling of mental exhaustion in the evening, and (5) psychosomatic symptoms during sleep. The remaining questions address sleep-related aspects of the prior night that were not relevant for our study.

Current psychological wellbeing was assessed with the Basler rating scale (Hobi, 1985). It offers 16 items consisting of a pair of alternative adjectives. Subjects are asked to choose the 16 alternatives that most accurately describe their current state of mood and psychological activity. For evaluation, items are grouped into 4 factors (the scores over all items within each factor are added): (1) mental and physical vitality, (2) intra-psychic balance, (3) degree of social extroversion (the ability and willingness to form social contacts), and (4) vigilance (ability to direct one's attention to something new).

Psychological well-being over the past week was rated with the Profile of Mood State (POMS). A German short version of the POMS (Bullinger et al., 1990) offers 35 items consisting of mood-descriptive adjectives that subjects rate according to their current state of wellbeing. Items are grouped into 4 sub-scales: depression, fatigue, vigor, and anger.

Attached to a standard socio-demographic questionnaire, we assessed self-reported consumption of stimulants per day: tobacco (yes/no; how many cigarettes), alcohol (separate for beer, wine, and liquors, measured in mL), and caffeine (separate for coffee, tea, caffeinated soft drinks, *e.g.*, cola, in mL). To make these quantities comparable, we calculated a value of alcohol and caffeine consumption. One unit of alcohol ('restaurant unit' corresponding to approximately 14 g of alcohol) can be represented by a bottle of beer (0.5 L), a glass of wine ($\approx$0.25 L), or a drink of liquor ($\approx$0.02 L) (Strandberg et al., 2004). Reference values of caffeine (per 100 mL) for the respective drinks were set as the following: coffee = 57.4 mg, tea = 27.0 mg, cola = 13.0 mg (Bunker and McWilliams, 1979; Vik et al., 2003). Especially the caffeine units must be considered as rough estimates, since the methods of preparation for tea and coffee strongly influence the caffeine concentration in beverages, resulting in high variability.

Partial correlations with age and gender as controlled covariates were employed for the analysis of associations between MSF_{SC} and the other study variables. Significance levels were initially set to values of $p < 0.05$ (one-tailed for the directional hypotheses concerning the correlations, *i.e.*, that late chronotypes suffer more mental distress and consume more stimulants).

To resolve the risk of Type I errors (incorrect rejection of null hypothesis) within multiple comparisons, we could have corrected the alpha level according to Bonferroni. This, however, would have increased the possibility of Type II error (false acceptance of null hypothesis). We, therefore, chose a conservative alpha level of 0.01.

RESULTS

The distribution of chronotypes (judged by MSFsc, see *Materials and Methods*) in the sample population used for this study (N = 501; black bars in Figure 1) is close to that of the general population (N = 35,000; grey bars in Figure 1; *status quo* of an ongoing survey, predominantly in

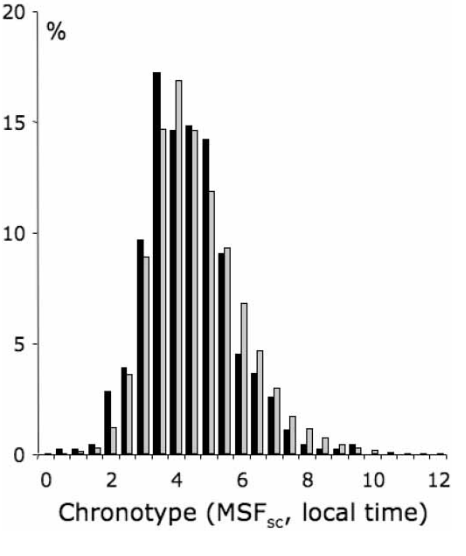

FIGURE 1 Distribution of chronotype (MSF_{sc}) in our sample of 501 participants (*black bars*) and compared with the population (black bars; main data base of N = 35,000 participants of an ongoing survey, predominantly in Germany, Switzerland, and Austria). Chronotype "0" includes all chronotypes with mid-sleeps earlier than or equal to midnight, chronotype 0.5 includes those who mid-sleeps are later than midnight and 00:30 a.m. (00:30 h), etc.

Germany, Switzerland, and Austria), although late types are slightly under-represented and early types slightly over-represented in our sample. The distributions of women and men showed no differences ($t = 1.7$, $p = 0.091$). As previously demonstrated for the general population (Roenneberg et al., 2004), the mean values for chronotype, as well as the width of its distribution, decreases with age (see first line in Table 1). This trend is highly significant over all groups (ANOVA: $F_{(3,465)} = 44.1$, $p < 0.001$) as well as between age groups (all Scheffé *post hoc tests*: $p < 0.01$, with the exception of the difference between the age group 41 to 60 yrs and >60 yrs, which did not reach the significance level).

Partial correlations between chronotype (corrected for age and gender effects) and sleep quality (SF-A), current psychological wellbeing (Basler rating scale), psychological wellbeing over the past week (POMS), and stimulant consumption showed mild to moderate associations (Table 1, column 1). Specifically, late chronotypes feel more worn out and tired in the evening (mental exhaustion) ($r = -0.112$, $p < 0.01$), report feeling less well at present (intra-psychic balance; $r = -0.111$, $p < 0.01$) as well as during the past week (depressed mood; $r = 0.114$, $p < 0.01$; Figure 2A). The consummation of stimulants is also significantly higher in late chronotypes who are more likely to consume caffeinated soft drinks ($r = 0.124$, $p < 0.01$; Figure 2B), are more frequently smokers ($r = 0.272$, $p < 0.001$; Figure 2C), or alcohol consumers ($r = 0.193$, $p < 0.001$; Figure 2D).

When inspecting the associations separately for different age groups (Table 1, columns 2 to 5), correlations between chronotype and the other measures are more often significant in the youngest age group (14 to 25 yrs), *i.e.*, for sleep quality ($r = -0.235$, $p < 0.01$), mental balance in the evening ($r = -0.265$, $p < 0.01$), being a smoker ($r = 0.405$, $p < 0.001$), likelihood of being an alcohol consumer ($r = 0.446$, $p < 0.001$), and overall amount of alcohol consumption (in ml; $r = 0.375$, $p < 0.001$), specifically for beer ($r = 0.287$, $p < 0.001$). A correlation between chronotype and the amount of wine consumption ($r = 0.294$, $p < 0.001$) exists only in subjects between 41 and 60 yrs of age. The higher likelihood for a late chronotype to be a smoker persists in the adult age groups but is only absent in the elderly (Table 1, column 5). The elderly show no significant correlations between chronotype and the other measures, except for the fact that early elderly chronotypes are more balanced in the evening than late elderly chronotypes ($r = -0.274$, $p < 0.01$), *i.e.*, they are more relaxed, carefree, and even-tempered.

DISCUSSION

The aim of the present study was to investigate associations between chronotype, quantitatively assessed by the MCTQ (Roenneberg et al.,

TABLE 1 Partial Correlation Coefficients Between Chronotype (MSFsc) and the Variables of Sleep Quality, Momentary Psychological Wellbeing (Basler), Psychological Wellbeing over the Past Week (POMS), and Stimulant Consumption

Correlation coefficients of variables with chronotype (MSF_{sc})	All ages N = 501	14 to 25 yrs N = 120	26 to 40 yrs N = 144	41 to 60 yrs N = 121	>60 yrs N = 116
Mean MSF_{sc} ± S.D. in local time ± h:mm		4:55 a.m. ± 1:17	4:25 a.m. ± 1:17	3:42 a.m. ± 0:46	3:17 a.m. ± 0:46
Sleep questionnaire SF-A					
1. Sleep quality	−0.107*	**− 0.235****	−0.087	0.37	−0.143
2. Sleep-dependent recovery	−0.062	−0.122	−0.001	−0.057	−0.202*
3. Mental balance evening	−0.100*	**− 0.265****	−0.001	0.64	**− 0.274****
4. Mental exhaustion evening	**0.112****	−0.186*	0.032	−0.190*	−0.202*
5. Psychosomatic symptoms	0.039	0.179*	−0.130	0.58	−0.160
Basler rating scale					
1. Vitality	−0.049	0.020	−0.060	−0.126	−0.002
2. Intrapsychic balance	**− 0.111****	−0.054	−0.143*	−0.220*	0.118
3. Social extraversion	0.028	−0.063	0.012	−0.132	0.156
4. Vigilance POMS	−0.076	−0.062	−0.107	−0.103	−0.100
1. Depressed mood	**0.114****	0.172*	0.084	0.098	0.102
2. Fatigue	0.036	−0.085	0.044	−0.076	−0.052
3. Vigor	0.064	−0.116	−0.061	0.059	0.028
4. Anger	0.043	0.048	0.036	−0.164*	0.061
Stimulants consumption					
1a. Smoking (Y/N)	**0.272*****	**0.405*****	**0.231****	**0.271****	0.049
1b. Number of cigarettes/day (if smoker)	−0.010 (*n* = 134)	0.220 (*n* = 51)	−0.197 (*n* = 40)	−0.008 (*n* = 32)	−0.480 (*n* = 11)
2a. Amount of beer/day	0.066	**0.287*****	−0.027	0.055	−0.086
2b. Amount of wine/day	0.055	0.013	−0.040	**0.294*****	0.108
2c. Amount of liquor/day	**0.120****	0.194*	0.092	-/-	0.118
2d. Overall drinks/day	**0.143*****	**0.375*****	0.016	0.200*	0.105
2e. Drinking alcohol (Y/N)	**0.193*****	**0.446*****	0.173*	0.142	0.058
3a. Amount of coffee/day	**− 0.119****	−0.096	−0.164*	−0.178	0.053
3b. Amount of tea/day	0.022	−0.016	0.051	−0.036	0.107

(*continued*)

TABLE 1 Continued

Correlation coefficients of variables with chronotype (MSF_{sc})	All ages N = 501	14 to 25 yrs N = 120	26 to 40 yrs N = 144	41 to 60 yrs N = 121	>60 yrs N = 116
3c. Amount of caffeinated soft drinks/day	**0.155*****	0.197*	**0.182****	0.122	−0.033
3d. Drinking caffeinated soft drinks Y/N	**0.124****	0.173*	0.132	0.059	−0.053
3e. Overall amount of caffeine/day	−0.087*	−0.079	−0.097	−0.186*	0.107

Correlation coefficients '*r*' are separately displayed for the different age groups. The effects of age and gender are factored out as covariates. *$p < 0.05$ (not significant after alpha-value adjustment), **$p < 0.01$, and ***$p < 0.001$; significant correlations are shown in bold.

2003b), subjective ratings of mood, sleep quality, and stimulant consumption. Late chronotypes experience more mental exhaustion in the evening, they feel psychologically less well both in reference to the present time (*i.e.*, lower mental balance) and in reviewing the past week (*i.e.*, higher depression scores, Figure 2A). These results support earlier findings (Chelminski et al., 1999; Giannotti et al., 2002; Mecacci and Rocchetti, 1998) and are in accordance with the fact that late types often report poor sleep and frequent daytime sleepiness (Giannotti et al., 2002; Taillard et al., 2003; Volk et al., 1994). Although the earlier work predominantly focused on young people using the morningness-eveningness score, here we address all age groups using a highly quantitative chronotype assessment of the MCTQ.

Concept of "Social Jetlag"

Societal determination of work times, and sometimes also of free times, interferes with individual sleep preferences. In late chronotypes, the constraints of early work schedules lead to an increasing sleep debt over the week that is compensated for on weekends. The fact that many people in our society shift their sleep and activity times several hours between the work week and the weekend (or other free days) is comparable to jetlag. As a first approach, this 'social jetlag' can be quantified by calculating the absolute difference between mid-sleep on workdays (MSW) and mid-sleep on free days (MSF): $\Delta MS = |MSF\text{-}MSW|$. Consequently, 'social jetlag' is most pronounced in late types, who substantially have to readjust their temporal habits to social demands (*i.e.*, having to get up early without being able to advance their circadianly controlled sleep-onset). Social jetlag is minimal in chronotypes who sleep at the

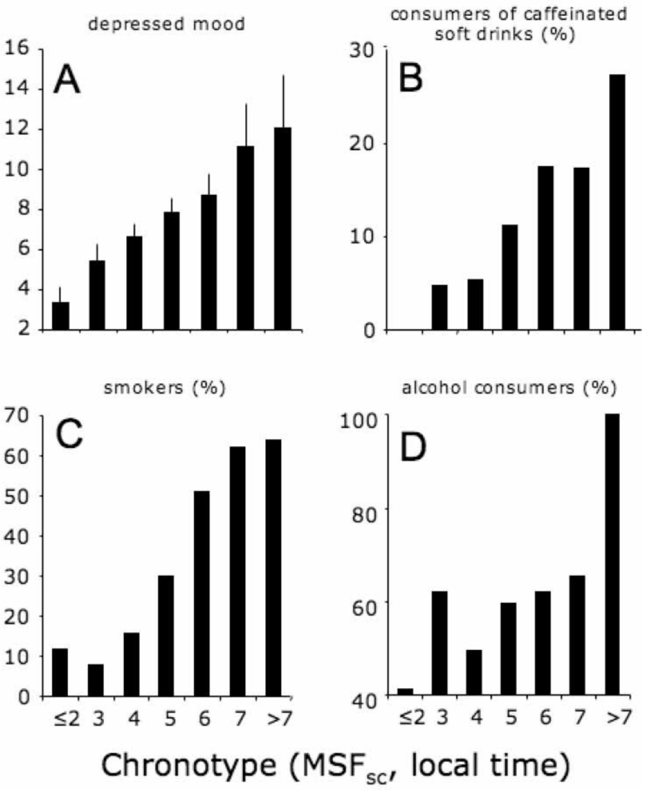

FIGURE 2 Mood ratings and stimulant consumption by different chronotypes over all subjects (MSF_{sc}). ***A:*** Depressed mood as reported in the POMS for psychological wellbeing over the past week, ***B:*** Percentage of people who drink caffeinated soft drinks, ***C:*** Percentage of people who smoke cigarettes, ***D:*** Percentage of people who drink alcohol (beer, wine, and hard liquors). SEMs are shown for the average scores in *A*.

same times on work and on free days (MSFsc ~3 a.m.; Figure 3A). People in this chronotype category also show the least differences in sleep duration between work and free days based on the general population (data not shown). To some extent, social jetlag also exists in early types on free days (Figure 3A) when they stay up late into the night without the possibility of sleeping longer the next morning due to their normal circadian wake-up time.

A good indication that the correlations between chronotype, lower sleep quality, and higher stimulant consumption (Figure 2) are a consequence of 'social jetlag', rather than of chronotype, itself exists for smoking habits, which show correlations in all age groups except retirement ones (Table 1). Chronotypes with a MSFsc of 3 a.m. (03:00 h) suffer the least social jetlag (Figure 3A) and are also least likely to be smokers (Figure 2C). When smoking habits are plotted against social jetlag, the distribution changes from an asymmetrical U-shape function

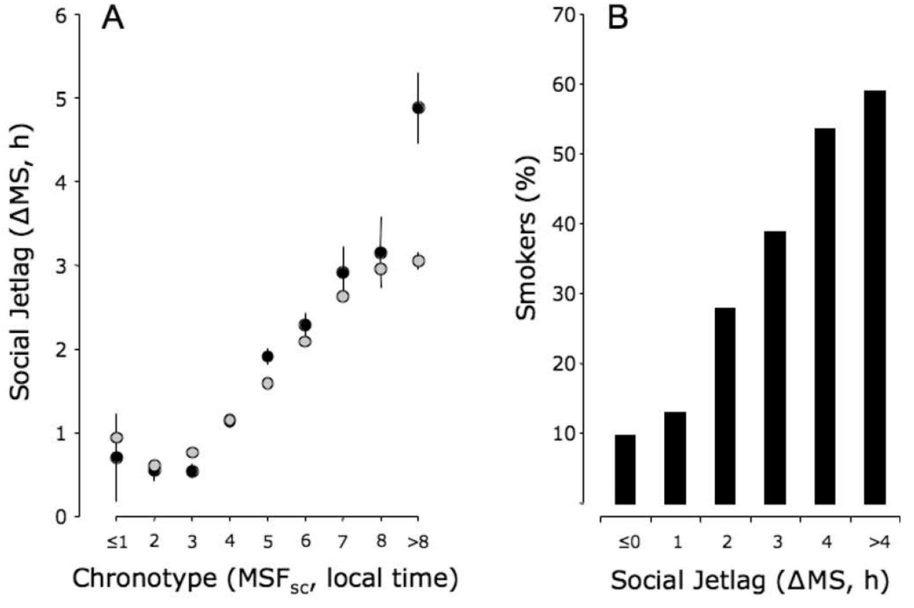

FIGURE 3 ***A:*** Correlation between chronotype (MSF_{sc}) and social jetlag. *Grey dots* represent the general database (see text: N = 35,000) and black dots the sample investigated in this study. ***B:*** Distribution of the percentage of smokers in each social jetlag subgroup.

to a linear trend (Figure 3B). When the extreme chronotypes whose MSFsc values ≥7 a.m. (07:00 h) strongly bias the correlation are omitted, positive correlations between smoking and social jetlag are even higher than those between smoking and chronotype. A strong argument for social jetlag (rather than simple chronotype) being responsible for smoking habits exists in the elderly. This age group is characterized by a relatively early average MSFsc and a relatively narrow distribution compared to persons of younger ages, and smoking habits and chronotype do not correlate (Table 1). Only 64% of the participants older than 60 yrs of age were retired. When the 36% who were still working are analyzed separately, smoking habits and chronotype are still independent, but a significant correlation is detected between smoking habits and social jetlag ($r = 0.36$; $p = 0.02$).

Consequences of Social Jetlag

Thus, although difficult to dissociate without further surveys and experiments, it seems as if it is not simply chronotype but its consequence, *i.e.*, social jetlag, that appears to be the primary cause for the higher probability of smoking. Although not as clear as in the case of smoking, this might also hold true for the probability of consuming alcohol and caffeinated soft drinks and possibly also for the higher scores of depressed mood. It is interesting that the quantity of cigarettes does not correlate with either chronotype or social jetlag, indicating that having started to smoke or not having been able to quit are the smoking-related parameters affected by social jetlag. Puberty and adolescence are the most likely times when people become smokers and this age group is also the most challenged by social jetlag. The statistics available for the region where this study was conducted indicate that 20.3% of the 15 to 20 yr old population smokes; smoking increases further to 35.4% in those 20 to 25 yrs of age (www.destatis.de/basis/e/gesu/gesutab7.htm). Thereafter, the percentage of smokers decreases with age, as does social jetlag due to late chronotype. A telephone survey of almost 8,000 US adolescents found a significant association of smoking and depressive symptoms with sleep problems (Patten et al., 2000). The authors concluded that a "reduction of depressive symptoms and cigarette smoking among adolescents is important factors to consider in prevention and treatment efforts focused on adolescent sleep problems." The study presented here includes chronotype as an important factor in the association between sleep problems and smoking or depressive symptoms and strongly indicates that the causalities hypothesised by Patten and coworkers (2000) might be reversed: a reduction of social jetlag among all age groups is an important factor to consider in prevention of smoking and depressive symptoms.

As students who are evening types are known to achieve less well in school (Giannotti et al., 2002), possible causal links between sleep behavior as expression of chronotype, cognitive abilities, and substance abuse should be considered. Insufficient sleep interferes negatively with daytime functions, possibly leading to long-term negative consequences in life achievements. Resulting coping strategies, such as smoking and drinking would add to these negative effects. Adolescents and young adults would greatly benefit (possibly with life-long positive consequences) if more attention were paid to their circadian biology, for example, if starting times in school were re-evaluated. Our results also support the necessity for adapting work schedules, *i.e.*, allowing more flexible work times that address an employee's chronotype (Petru et al., 2005). With growing knowledge and awareness of the social importance of circadian biology, society must start adapting the temporal organization of society to the needs of human behavior and, thereby, overcome the discrepancy between social and biological timing, which we suggest be called 'social jetlag.' The big difference between transmeridian and social jetlag is that the former is transient and concerns relatively few people, while the latter is chronic and concerns the majority of the population in industrialized countries. Social jetlag can be corrected only by sweeping changes in the organization of society.

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