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ORIGINAL ARTICLE

Chronotype as self-regulation: morning preference is associated with better working memory strategy independent of sleep

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Abstract

Study Objectives: We set out to examine how chronotype (diurnal preference) is connected to ability to function in natural conditions where individuals cannot choose their sleep schedule. We conducted a cross-sectional study in military conscript service to test the hypothesis that sleep deprivation mediates the adverse effects of chronotype on cognitive functioning. We also examined the effects of time of day.

Methods: One hundred forty participants (ages 18–24 years) completed an online survey, including the Morningness-Eveningness Questionnaire and a Cambridge Neuropsychological Test Automated Battery. Most (*n* = 106) underwent an

Statement of Significance

Chronotype is associated with many outcomes; morning persons perform better academically, while eveningness is associated with non-beneficial health outcomes. Evening persons' exposure to sleep deprivation in school and work may explain some of these differences. We examined the connection between morning/evening preference, cognition, and sleep in military conscript service, where individuals cannot choose their sleep schedule. Morning preference was connected to performance strategy only, regardless of current sleep. This suggests that morning preference may reflect strategic planning and self-regulation, which could explain why so many beneficial outcomes are connected to morningness. Future research should address how both biological and behavioral morning-evening preferences are related to strategies of navigating everyday problems, and how they promote adaptation in different environments.

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actigraphy recording. After bivariate analyses, we created a mediation model (self-reported sleepiness and sleep deprivation mediating effect of chronotype on cognition) and a moderation model (synchrony between most alert time and testing time).

Results: Reaction times in inhibition task correlated negatively with sleep efficiency and positively with sleep latency in actigraphy. There was no relation to ability to inhibit responses. More significantly, spatial working memory performance (especially strategicness of performance) correlated positively with morning preference and negatively with sleep deprivation before service. Synchrony with most alert time of the day did not moderate these connections. No other cognitive task correlated with morningness or sleep variables.

Conclusions: In line with previous research, inhibitory control is maintained after insufficient sleep but with a tradeoff of slower performance. The connection between morning preference and working memory strategy is a novel finding. We suggest that diurnal preference could be seen as an adaptive strategy, as morningness has consistently been associated with better academic and health outcomes.

Key words: actigraphy; circadian rhythms; cognitive function; executive function; neuropsychology; sleep deprivation

Introduction

The human circadian rhythm follows a cycle of approximately 24 h. The interaction of the appetitive homeostatic sleep drive and the endogenously oscillating circadian clock produces the observable sleep/wake cycle [1]. During this cycle, changes occur in many physiological and psychological functions. Chronotype refers to variation between individuals in their disposition for sleep timing and being at their most alert at different times of the 24-hour day. Chronotype can be conceptualized as a continuous biological construct that is based on an individual's genetic makeup, but which can dynamically change with entraining conditions [2].

In twin and family studies, heritability of chronotype has been estimated to be approximately 50% [3, 4]. In epidemiological studies, chronotype has been found to be near-normally distributed with age- and sex-dependent variation. Chronotype (midpoint of sleep) is earlier in childhood and becomes progressively later during development. In women, chronotype is most delayed (latest) at 19.5 years of age, and in men at 21 years. After this, chronotypes advance (become earlier) with increasing age, but men continue to average later chronotypes until the male-female difference disappears around 50 years of age [5]. Pertinent to our study, young men may thus be at greater risk for sleep loss in conditions where earlier sleep/wake schedule is imposed. However, a Finnish study on chronotype (diurnal preference) found evening preference to be more common among women and morning preference among men, but after age 25 years in both men and women, the proportion of morning preference types increased with age [6].

Eveningness has been associated with many health problems, including obesity and metabolic disorders [7, 8], depression [9], and bipolar disorder [10]. In a genome-wide association study, morningness was genetically negatively correlated with depression and schizophrenia, and positively with well-being [11]. But studies on chronotype and cognitive ability have found contradictory results: In a meta-analysis of 11 studies by Preckel et al. (2011), five reported a positive correlation between morningness and cognitive ability and seven a negative correlation, while for eveningness there were six positive correlations and one negative. They found no reliable meta-analytic results were found [12]. This may result from the varying cognitive measures used in the original studies. There are also factors that can mediate and moderate the association between chronotype and performance, which we review next.

Morningness is associated with better academic performance, which has been attributed to synchrony between school work schedules and morning types' optimal time of working [12, 13]. Individuals engage in more systematic processing of information at their chronotypically optimal time of day [14, 15]. Self-reported mind-wandering, daydreaming, and attentional errors peak at the non-optimal time of day [16]. At nonoptimal times, lapses in attentional regulation result in larger, partly irrelevant bundles of information being encoded to memory [17, 18]. In a study of executive function, morning type early adolescents performed better than evening types in the morning, and evening types better than morning types in early afternoon [19]. The findings on lapses in attention may be related to the finding that visual fixation times increase at chronotypically nonoptimal times of the day, and this correlates with subjective fatigue [20]. But in a study where participants performed in an attention task at the beginning and end of an 18-hour period of sustained wakefulness, those with tendency for morningness had longer reaction times in the morning, while those with tendency for eveningness had longer reaction times late at night [21]. These slightly contradictory findings in a wide body of research may result from generalized assumptions on the optimal working times based on chronotype, from the use of varying cognitive measures, or from noncontrolled misalignment of social and biological rhythms in participants.

A discrepancy between chronotype and environmental pressures on sleep schedule can expose individuals to sleep deprivation. Sleep deprivation has been connected to a wide range of cognitive changes, including diminished attention, processing speed, and working memory performance [22] and changes in reciprocal activations of brain networks [23]. Sleep, chronotype, and time of day interact: A study on psychomotor vigilance in predominantly late-chronotype shift-workers found (expectedly) that performance was weakest during morning shift, but sleep debt affected performance only during morning shift, which may reflect the adequacy of sleep at other times of the day [24]. But even the common 5-day work week can impose a discrepancy on biological and social clocks, which is captured by the concept of social jetlag [2]. A mouse model found that a cycle of 2 days of delayed light/dark conditions and 5 days of normal light/dark conditions resulted in delayed biological rhythms and impaired performance in a learning and memory task [25]. In human adolescents, social jetlag correlated negatively with areas of cognitive performance (reasoning, spatial, and numeric abilities) while morningness-eveningness did not [26].

There is evidence also of individual variation in vulnerability to sleep deprivation. Top- and bottom performers in a psychomotor vigilance task during 41-hour sleep deprivation differed only in baseline executive function abilities, not in other areas of cognitive performance nor regarding morningness-eveningness [27]. But in a functional magnetic resonance imaging (fMRI) study, sleep pressure (one-night sleep deprivation) interacted with clock gene PER3 polymorphism during a working memory task: [28] Compared to those with the vulnerable genotype (associated with morningness [29, 30]), those with the less-vulnerable genotype were better able to maintain cortical activity and also recruited supplemental brain areas to uphold executive function. In another fMRI study conducted at morning, 24 h of sleep deprivation led to increased response times in a go/no-go task but did not impair response accuracy, while evening types performed worse than morning types regardless of the presence of sleep deprivation [31]. Neural-level results indicate that sleep deprivation decreased inhibition-related activation in right lateral inferior frontal gyrus with morning types but increased activation in this area with evening types, which may indicate a compensatory reaction as it correlated with subjective sleepiness and effort put to the task.

The aim of the present study is to examine the relationship between chronotype (diurnal preference) and cognitive performance in an environment where individuals cannot choose their sleep schedule (conscript military service) and are thus exposed to greater risk for sleep deprivation. Our study also attempts to improve on earlier research by (1) introducing a naturalistic yet controlled setting, (2) employing a standardized neuropsychological test battery, and (3) operationalizing synchrony directly from the preferred working hours of the participants.

Based on previous research, we propose the following set of hypotheses:

1. Under these conditions, morning preference correlates positively with cognitive performance in tasks requiring attention, executive control, or working memory.
2. Sleep deprivation, sleepiness, and sleep efficiency mediate the connection between morning preference and cognitive performance.
3. Synchrony between the preferred most alert time and performance time moderates the association between morning preference and cognitive performance.

Methods

Data were collected as part of the project *Sleep as a predictor of mental wellbeing and ability to function* from young adults conscripted in military service in 2016–2018 in the anti-aircraft company of the Karelia Brigade. The participants completed a comprehensive survey, a Cambridge Neuropsychological Test Automated Battery (CANTAB), and an actigraphy recording.

Altogether 211 individuals were invited to participate in the study, and 172 individuals decided to participate (see Supplementary Table S1 for details). The CANTAB results included some clear outliers, indicating a possible lack of motivation or performance orientation. Mahalanobis distances were calculated to detect multivariate outliers and eight participants screened out at a probability level of .001. The outliers did not differ with respect to psychiatric or demographic measures where this could be computed (only four of the outliers had completed the survey). The main analyses were performed for the remaining 140 non-outliers who had completed both the survey and the test battery. Of these individuals, 112 had completed actigraphy, while 15 participants wore the wrist actigraph only for a few days and 13 did not use it at all. Of these 112 completed recordings, 6 were excluded for technical reasons or because the individual was on an outdoor mission, leaving 106 participants.

All participants were screened for medical conditions prior to entering service and again during the first 2 weeks of service, before entering the study. None had clinical depression or any other medical condition that could have had a profound effect on ability to function.

In the brigade participating in the study, sleep is scheduled between 22 and 6. This is an early sleep schedule: In Finnish schools working hours cannot begin before 8 o'clock in the morning and often begin later. Also, in a database of over 185,000 Munich ChronoType Questionnaire participants, the most common sleep schedule on free days corrected for sleep debt was from 23:30 to 7:30, with only 29.4% sleeping earlier [2].

Survey data

The online survey included Finnish versions of the Morningness-Eveningness Questionnaire (MEQ, 6 questions) [32, 33], the Beck Depression Inventory (BDI, 21 questions) [34], the Overall Anxiety Severity and Impairment Scale (OASIS, 5 questions) [35, 36], the Resilience Scale (RS, 14 questions) [37, 38], the Sense of Coherence scale (SOC, 13 questions) [39], and for both the situation before and during service the Epworth Sleepiness Scale (ESS, 8 questions) [40]. Participants were also asked how much sleep per night they needed to feel refreshed, how much they slept before and during service, their grade point averages (GPAs) at the end of 9 years of comprehensive school, and their alcohol use. Sleep deprivation was then calculated as the arithmetic difference between the need for sleep and actual sleep; if this resulted in a negative value, it was set to zero for conceptual reasons. The survey included also other questions and scales not covered by the present study.

In missing value analysis, there were very few (≤0.4%) missing values for most of the scales. These were replaced with item medians. ESS during service had many missing values in item 3 due to a technical error in the survey (38.9%). These were replaced with the median of the answers given by the same participant for three other similar questions in the scale.

Measurement of cognitive performance

For measurement of cognitive performance, the participants completed six subtests from the computerized CANTAB (research suite version): [41]

- *Attention Switching Task* (*AST*) for cued attentional set shifting.
- *Motor Screening Task* (*MOT*) for screening difficulties in vision, movement, and comprehension.
- *Paired Associates Learning* (*PAL*) for visual memory and learning.

- *Rapid Visual Information Processing* (RVP) for visual sustained attention and in addition as a sensitive measure of general performance.
- *Spatial Working Memory* (SWM) for retention of spatial information and manipulation of remembered items in working memory. The participant must search for a hidden token from a set of boxes and minimize the number of boxes opened. There is no time pressure, but as a self-ordered task, it requires formation of a heuristic strategy.
- *Stop Signal Task* (*SST*) for ability to inhibit a prepotent response. The participant must respond to an arrow stimulus by selecting the arrow direction. If an audio tone (the stop signal) is present, the participant must stop making the response. Stop signal task estimates the covert latency of this inhibited response by adapting the delay at which the stop signal is presented, so that the rate of inhibition errors is 50%.

MOT was included in the battery for screening outliers, and after outlier analysis was excluded from further analyses, as it does not measure the hypothesized cognitive functions. PAL, RVP, and SWM were selected because they measure core cognitive functions and are among the most researched CANTAB tests. AST and SST were selected because they measure attention and executive function, and should thus be sensitive to sleep deprivation. In our data, AST, PAL, RVP, and SWM performance showed highly significant intercorrelations (see Supplementary Table S2).

Cognitive measurement took place on average 57 days (SD 39) from service start. Participants could not choose the date or time of day for their CANTAB session; this was determined by the research assistants (conscript medics).

Objective estimation of sleep

For objective estimation of sleep amount and quality, participants used a wrist actigraph, which recorded motor activity day and night, and filled in a sleep log [42]. In actigraphy sleep analysis, if the subject is immobile for long periods of time during the night, their sleep is probably peaceful, and sleep quality is considered good. If there is a lot of movement during the sleep period, sleep quality is considered poor. This may result in inaccuracies, but estimation of sleep quality by actigraphy is associated with sleep being restorative and restful, and in subjects without organic sleep disorders, sleep efficiency in actigraphy correlates with sleep efficiency in polysomnography [43].

Recordings lasted a week and analyses were done using MotionWare (CamNtech Ltd, Cambridge, UK). The epoch length was 1 min and the algorithm for wake threshold was set to high sensitivity, which is recommended when subjects with less sleep problems are investigated. High sensitivity threshold means that the smallest amount of movement is scored as wake, and thus, the algorithm is very sensitive to disruptions in sleep. For this study, recordings were analyzed for actual sleep time, sleep efficiency, bedtime (lights out), and time of falling asleep on a Tuesday night. Actual sleep time was defined as the amount of sleep between sleep start and sleep end, wake time excluded, as determined by the algorithm. Sleep efficiency was defined as the percentage of time spent asleep between bedtime and time getting up. Sleep latency was defined as the difference between bedtime and time of falling asleep. Tuesday night was chosen because it was not an off day for any of the participants: they all spent the evening in the barracks and thus could not choose their sleep schedule.

We found out post hoc that in practice actigraphy recordings had not been done synchronously with CANTAB testing. Thus, when analyzing connections between cognitive performance and objective sleep, we limited the data to those for whom CANTAB testing was done at most seven days after the actigraphy on Tuesday ($n = 34$). As this was an arbitrary limit, we experimented also with 1- and 3-day limits, but this did not significantly change the results.

Data analysis strategy

Data analysis was performed using IBM SPSS Statistics version 25. Moderation and mediation analyses were performed using Andrew F. Hayes' Process Macro, version 3.5 [44].

CANTAB produces a very large number of metrics for each test. Principal component (PC) analysis is a valid technique for summarizing CANTAB data [45]. To alleviate the problems of metric selection and multiple comparisons, we adopted this strategy. Each of the five tests was reduced to a single PC. As all PC distributions were not normally distributed and most of them were skewed, we employed nonparametric and bootstrapping methods in subsequent analyses.

We proceeded with a set of subsequent analyses to test our hypotheses. We controlled the effects of psychiatric symptoms (BDI and OASIS), everyday functionality (SOC and RS), primary cognitive capacity (GPA), and habituation to military service (days from service start to CANTAB testing). When significant associations with the PCs emerged, a more detailed analysis of component metrics was performed to investigate the cognitive processes involved. Creation of mediation and moderation models is described in the Results section.

Results

Sample characteristics

As conscript service is obligatory for young men and voluntary for women in Finland, the sample is almost completely of male gender (93.6%) and of similar age (19.45 years with 0.98 SD). Sample characteristics and self-report data are presented in Table 1 and objective sleep data in Table 2. For illustrative purposes, they have been divided into discrete chronotypes (morning/intermediate/evening) according to Finnish cut-off points for MEQ [33]. To avoid loss of information, the statistical tests below have been performed using the continuous MEQ score as a measure of morning preference.

Hypothesis 1: morning preference is positively correlated with cognitive performance

Morning preference (MEQ score) was positively and significantly correlated with the PC for the SWM task (Spearman's $\rho = .246$, $p = .003$); the correlation remained significant after Bonferroni correction for multiple comparisons. Morning preference was not significantly correlated with PCs for other CANTAB tasks (see Table 3).

Associations with possible confounding variables are presented in Supplementary Table S3. Depression scores (BDI) correlated significantly and negatively with morning preference ($\rho = -.254$, $p = .002$). GPA correlated significantly and positively with SWM performance ($\rho = .277$, $p = .001$). As the correlation between resilience and morning preference approached significance ($\rho = .147$, $p = .083$), we further tested four questions related to everyday functionality from the RS of which the question "I have self-discipline" correlated positively and highly significantly with morning preference ($\rho = .302$, $p < .001$). When the effects of these variables were controlled with partial correlations, the correlation between morning preference and SWM performance remained in all cases highly significant ($p \leq .010$).

When the measures comprising the SWM PC were analyzed separately (see Supplementary Table S4), morning preference was significantly and negatively correlated (indicating better performance) with measures of strategy ($\rho = -.263$, $p = .002$), number of between-search errors in the most challenging subtasks ($\rho = -.237$, $p = .005$), and mean performance time ($\rho = -.215$, $p = .011$). See further description of these measures in the Discussion section. The three measures were strongly intercorrelated ($0.551 \leq \rho \leq 0.754$). When the effect of strategy (the strongest correlation) was controlled using partial correlations, the two other measures no longer correlated significantly with morning preference.

Hypothesis 2: sleep variables mediate the effect of morning preference on cognitive performance

Before service, morning preference correlated negatively with self-reported sleep deprivation ($\rho = -.184$, $p = .029$) and sleepiness (ESS score; $\rho = -.312$, $p < .001$). During service morning preference correlated negatively with sleep deprivation ($\rho = -.282$, $p = .001$) and sleepiness ($\rho = -.302$, $p < .001$). The only self-reported sleep variable to correlate significantly with CANTAB components was sleep deprivation before service, which correlated negatively with SWM performance ($\rho = -.195$, $p = .021$). Of individual SWM measures, it correlated positively with strategy ($\rho = .283$, $p = .001$) and number of search errors in the most challenging subtasks ($\rho = .296$, $p < .001$), and less significantly ($p < .05$) with search errors in less challenging tasks. See Supplementary Tables S4 and S5 for details.

In actigraphy, morning preference did not correlate significantly with actual sleep time ($\rho = .164$, $p = .094$) or sleep latency ($\rho = -.092$, $p = .353$) but correlated positively with sleep efficiency ($\rho = .192$, $p = .048$). Both sleep efficiency ($\rho = -.434$, $p = .010$) and sleep latency ($\rho = .400$, $p = .019$) correlated with SST performance but not with any other CANTAB components. The correlation with sleep efficiency was driven by highly significant correlations of sleep efficiency with mean correct reaction time on 'go' signals ($\rho = -.465$, $p = .006$) and with 50% stop signal delay ($\rho = -.463$, $p = .006$). The correlations with sleep latency were similar but weaker. See Supplementary Tables S6 and S7 for details.

SWM performance was the only CANTAB component significantly associated with both morning preference and sleep variables. We created a mediation model of the effect of sleep deprivation before service on the connection between morning preference and SWM strategy. We included other self-reported sleep variables as mediators for controlling purposes. The mediation model explained a significant proportion of variance in SWM strategy ($R^2 = .126$, $F(5, 134) = 3.876$, $p = .002$). In 5000 sample bootstrap analyses, only sleep deprivation before service had an indirect effect that differed from zero at the 95% confidence interval (see Supplementary Table S8 for details). However, the direct effect of morning preference on SWM strategy remained significant in this model ($B = -0.316$, $t(134) = -2.118$, $p = .036$). We created a similar model with SWM errors in the most challenging subtasks, yielding similar results (model summary $R^2 = .129$, $F(5, 134) = 3.955$, $p = .002$; direct effect of morning preference $B = -0.601$, $t(134) = -2.083$, $p = .039$; see Supplementary Table S9 for indirect effects).

Hypothesis 3: synchrony between preferred time and performance time moderates cognitive performance

In MEQ, question 5 was: "Suppose that you can choose your own work hours. Assume that you worked a five-hour day (including breaks) and that your job was interesting and paid by results. Which five CONSECUTIVE hours would you select?" Participants were free to choose any period of 5 hours during the day. We created a synchrony variable by taking the difference between the midpoint of the preferred working hours and the timestamp of the CANTAB session. The time of CANTAB session ranged from 6:37 to 17:51, with mean of 9:35 (SD 2:40). Preferred starting points for 5-hour day ranged from 6 to 24, with mean of 10:15 (SD 2:52). The synchrony variable ranged from 2 min to 294 min with a mean of 65 min (SD 59min).

The synchrony variable did not correlate significantly with any of the CANTAB components, although there was a possible trend with SWM performance (Spearman's $\rho = -.155$, $p = .068$). For control purposes, we entered the synchrony variable as a moderator into a regression model where MEQ score was used to predict cognitive performance. The moderation model explained a significant proportion of variance in SWM performance ($R^2 = .066$, $F(3, 136) = 3.220$, $p = .025$). MEQ score significantly predicted SWM performance ($B = -0.061$, $t(136) = 2.594$, $p = .011$) but no significant effects of synchrony (direct or interaction) were found (see Supplementary Table S10). We tested also whether the results would differ using SWM strategy measure or errors made in the most challenging subtasks, but the results were similar.

Discussion

We found that morning preference is associated with better SWM performance (less errors, faster total performance, and better strategy). This connection remained even after controlling for school performance, depression, anxiety, SOC, and resilience. In no other area of cognition (attention, episodic memory, inhibitory control, task switching) was performance connected to chronotype. Contrary to our hypothesis, this effect was not moderated by synchrony between the subjective most alert time and performance time.

We found a relationship between self-reported sleep deprivation before service and worse SWM performance (more errors and worse strategy). Sleep deprivation before service also mediated the effect of morning preference on SWM performance. The wide temporal window from the before-service situation to

Table 1. Self-report data for whole sample and breakdown by tripartite chronotype

	All	Morning types	Intermediate types	Evening types
n	140	27	80	33
Age	19.45 (0.98)	19.56 (1.22)	19.40 (0.88)	19.48 (1.00)
Gender (male)	93.6%	92.6%	93.8%	93.9%
Grade point average	4.50 (1.56)	4.81 (1.42)	4.48 (1.71)	4.30 (1.26)
Alcohol use (weekly)	2.01 (0.85)	1.89 (1.01)	1.92 (0.74)	2.30 (0.92)
Alcohol use (on single occasion)	3.26 (1.30)	3.04 (1.29)	3.10 (1.36)	3.82 (1.01)
BDI	4.36 (5.70)	2.52 (3.14)	3.80 (4.98)	7.21 (7.73)
OASIS	2.84 (3.08)	2.41 (2.87)	2.59 (2.74)	3.82 (3.82)
RS	78.01 (12.38)	81.00 (9.67)	78.59 (12.21)	74.18 (14.07)
SOC	65.88 (10.57)	67.70 (9.35)	66.87 (10.03)	61.97 (12.04)
MEQ	15.05 (3.70)	20.44 (1.83)	15.20 (1.63)	10.27 (1.44)
ESS before service (b.s.)	5.15 (3.21)	3.48 (2.28)	4.85 (2.76)	7.24 (3.82)
ESS during service (d.s.)	6.40 (4.04)	4.30 (2.81)	6.20 (3.66)	8.61 (4.72)
Sleep needed(hours) b.s.	8.27 (1.37)	7.91 (1.13)	8.08 (1.27)	9.03 (1.54)
Sleep (hours) b.s.	7.74 (1.38)	7.76 (0.99)	7.59 (1.18)	8.11 (1.95)
Sleep deprivation (hours) b.s.	0.85 (1.17)	0.32 (0.50)	0.84 (0.99)	1.33 (1.69)
Sleep needed(hours) d.s.	7.98 (1.22)	7.80 (0.92)	7.80 (1.18)	8.58 (1.37)
Sleep (hours) d.s.	6.83 (0.86)	7.30 (0.52)	6.79 (0.93)	6.55 (0.75)
Sleep deprivation (hours) d.s.	1.29 (1.25)	0.69 (0.80)	1.19 (1.12)	2.05 (1.49)

Standard deviations in parentheses.
BDI, Beck Depression Inventory, 21 questions; OASIS, Overall Anxiety Severity and Impairment Scale, 5 questions; RS, Resilience Scale, 14 questions; SOC, Sense of Coherence Scale, 13 questions; MEQ, Morningness-Eveningness Questionnaire, 6 questions; ESS, Epworth Sleepiness Scale, 8 questions; b.s., before service; d.s., during service.
For grade point average (actual grading scale 4-10), 1 = 6 or less, 2 = 6.1–7.0, 3 = 7.1–7.5, 4 = 7.6–8.0, 5 = 8.1–8.5, 6 = 8.6–9.0, 7 = over 9. For weekly alcohol use, 1 = 0 standard drinks, 2 = 1–7, 3 = 8–15, 4 = 16–23, 5 = 24 or more. For alcohol use on single occasion, 1 = 1–2 standard drinks, 2 = 3–4, 3 = 5–6, 4 = 7–9, 5 = 10 or more.

Table 2. Actigraphy data from a single night (Tuesday)

	All	Morning types	Intermediate types	Evening types
n	106	19	62	25
Actual sleep time (h:mm)	5:59 (1:00)	6:19 (0:53)	5:56 (1:05)	5:55 (0:52)
Sleep efficiency (%)	81.86 (8.40)	84.71 (7.68)	80.87 (9.30)	82.14 (5.96)
Bedtime (hh:mm)	22:41 (0:51)	22:41 (1:00)	22:35 (0:46)	22:54 (0:55)
Time of falling asleep (hh:mm)	22:56 (0:52)	22:50 (1:01)	22:52 (0:49)	23:09 (0:50)
Sleep latency (h:mm)	0:15 (0:20)	0:09 (0:11)	0:17 (0:24)	0:14 (0:15)

Standard deviations in parentheses.

Table 3. Correlations between MEQ score and principal components for CANTAB tests

	MEQ	
	Spearman's ρ	P
AST	.015	.864
PAL	.055	.522
RVP	-.011	.898
SST	.035	.679
SWM	.246	.003

All P-values are unadjusted for multiple comparisons.
MEQ, Morningness-Eveningness Questionnaire, 6 questions; CANTAB, Cambridge Neuropsychological Test Automated Battery; AST, Attention Switching Task; PAL, Paired Associates Learning; RVP, Rapid Visual Information Processing; SST, Stop Signal Task; SWM, Spatial Working Memory.

measurement points makes this statistical mediation effect difficult to interpret theoretically. It is, however, useful in relation to our finding that current sleep (self-reported or objective) had no effect on SWM performance. We also found a connection between reaction speed in the response inhibition task (stop signal task) and objective sleep efficiency in actigraphy. No other connections between cognitive performance and sleep variables were found.

This sparsity of hypothesized effects was unexpected. We note that similar preliminary results have been reported in an actigraphy study, where sleep parameters did not mediate the well-established connection between eveningness and depression [46]. Nor were sleep parameters connected to attention task performance (similar to CANTAB AST) in another recent actigraphy study [47]. We revisit some of our theoretical interpretations below.

Sleep and inhibitory control

The stop signal task is a well-researched paradigm that tests the ability to inhibit an already initiated response [48, 49]. In our results, better sleep efficiency and shorter sleep latency were not connected to the covert stop signal reaction times but were connected to faster observable reaction times. That they were also linked to shorter stop signal delays is unsurprising because in the SST model the probability of responding to a stop signal is lower the longer the primary task reaction time. This means that SST will present faster reacters with shorter stop signal delays [48].

In patient groups, lower sleep efficiency in actigraphy has been shown to be related to poorer cognitive performance, including slower processing speed [50, 51]. Deficient inhibitory control in SST has been found in individuals with insomniac disorder [52], and also in other psychiatric patient groups [53]. Results similar to ours were obtained when healthy participants were tested with tasks of sustained and selective attention after a night of total sleep deprivation; they did not make more errors, but their responses slowed more when the task required inhibitory control [54]. Similarly, in an electroencephalography study employing SST, controlled sleep deprivation contributed to a general slowing of reaction times in sustained attention but did not affect more automatic aspects of cognitive control such as response inhibition [55]. Taken together, the results suggest that in healthy individuals' inhibitory control is maintained after sleep deprivation or inefficient sleep, but this comes with a tradeoff of slower performance.

Morning preference and strategy

CANTAB SWM assesses the ability to formulate and maintain a heuristic strategy [41, 56]. This strategy measure has been associated with accuracy of performance in a patient and control groups, and various patient groups show worse use of the strategy [56–63]. The relationship between the CANTAB SWM task and more traditional neuropsychological tests is not straightforward; the error score has correlated with tests requiring attention and processing speed but not with working memory capacity. The strategy score only correlated with word list memory and semantic fluency [64]. None of the traditional tests assess strategy formation and application, but both semantic fluency [65, 66] and word list memory [67, 68] benefit from strategy use. This means that the CANTAB SWM task measures use of strategy in a way not directly captured by more traditional tests. Instead, it requires proactively adopting a novel task-appropriate mindset without external priming, and constantly updating the contents of working memory according to the strategy as the task progresses. These are considered central executive functions [69].

Thus, our study demonstrates an independent connection between performance strategy and morning preference. This connection has been suggested by some previous research [70–72], but not demonstrated in an explicit and measured way. Earlier research has also found strong connections between conscientiousness (personality factor) and morningness [73, 74], conscientiousness and executive function [75, 76], and conscientiousness and organized behavior in general [77–80]. Also, in our data, morningness was associated with subjective self-discipline (a facet of conscientiousness), but self-discipline was not associated with SWM strategy.

Executive functions measured by the SWM strategy are plausibly required in self-regulation tasks that support adaptive and organized behavior [81]. In everyday life, individuals can choose their sleep schedules, but during military service the schedule is imposed from outside, which reduces the need for executive control. We consider our finding that SWM strategy was connected to sleep deprivation before service but not during service to reflect this. Thus, our study suggests a behavioral level connection between diurnal preference and self-regulation abilities. It is a recurrent finding that morningness is linked to beneficial health outcomes and better academic performance [7–9, 12, 13]. Genetic disposition for morningness may facilitate goal achievement in contemporary social environments that are optimal for morning preference (behavioral morningness). But in addition to this, morning preference may also be a behavioral strategy an individual adopts regardless of their genetic disposition, to achieve their goals more effectively. We emphasize here that MEQ does not strictly measure chronotype (defined as phase difference between external and internal time), but rather temporal behavioral preferences [5]. More research with measurement of dim light melatonin onset [82] is needed to determine the relationship between biological chronotype and our findings.

It is noteworthy that in our study chronotype was not associated with performance in most of the cognitive tasks. Some studies have suggested a link between eveningness and intelligence, despite evening persons' worse academic performance [12, 83, 84]. This interpretation does not receive support from our study. We also find a contrasting view to this interpretation from contemporary models of intelligence in which adaptation to the environment is seen as an important aspect of intelligence [85]. Our study suggests that instead of taking diurnal preferences as markers for intelligence, we should look at how they support adaptation to environments such as school and work.

Limitations

Some limitations of the study design must be acknowledged. First, sleep deprivation was assessed based on self-report, which may be unreliable. Furthermore, self-report data on the before service situation were collected during service, at the same time point as the during service data. It is possible that the participants' answers do not adequately reflect the before service situation. However, as the participants reported more sleepiness and more sleep deprivation during service than in the before service situation, they seem to have been able to differentiate between the two time points.

Second, some aspects of the study were not in practice carried out according to the study design. Actigraphy recordings had not been done synchronously with CANTAB testing. This meant that connections between cognitive performance and objective sleep were analyzed using a smaller sample than planned (participants with a maximum of 7 days between actigraphy and CANTAB), limiting their statistical power. This also means that we do not have data on whether participants were restricted to 22:00–6:00 sleep schedule the night before their CANTAB session, but we consider that they most likely were, given the usual circumstances of conscript service in the studied garrison. Furthermore, the time of day for CANTAB testing varied more than we expected, and our operationalization of synchrony may not capture all circadian fluctuations in performance (e.g. sleep inertia in early morning).

Third, our sample was homogeneous regarding both age and gender. This may limit the generalizability of the results. At the same time, it should be noted that conscription is common in Finland, with 76% of the male age group being called to service in both 2015 and 2016, the rest excluded mostly for health reasons [86]. However, we note that CANTAB performance has been found to peak in early adulthood [87], and men have outperformed women in most tests (including SWM) [45, 87]. Also, as chronotypes are at their latest during adolescence, our sample is likely to lean towards late chronotypes compared with the general population, where the ratio of morning-evening preferences is the inverse. More research is needed to validate these results in other age and gender groups.

Conclusion

We studied sleep, cognitive performance, and diurnal preferences of military conscripts working on a fixed sleep/wake schedule. Our study revealed a connection between morning preference and strategicness of visuospatial working memory performance. The only sleep variable related to this performance was sleep deprivation before service. Timing of testing did not have a moderating effect. We also found that objective sleep efficiency was associated with performance speed when inhibitory control was required. No other cognitive function was linked to sleep or chronotype. The relationship between morning preference and strategy may reflect a self-regulatory connection between diurnal preference and strategicness of behavior, and explain why morningness has consistently been associated with better academic and health outcomes.

Supplementary Material

Supplementary material is available at *SLEEP Advances* online.

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Disclosure Statement

The authors have no financial or non-financial interests to disclose.

Data Availability

The data underlying this article cannot be shared publicly for ethical and institutional study permission reasons.

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