Individual differences in shift work tolerance
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“It is a common experience that a problem difficult at night is resolved in the morning after the committee of sleep has worked on it”

John Steinbeck
Chapter 4

Are individuals’ nighttime sleep characteristics prior to shift work exposure predictive for parameters of daytime sleep after commencing shift work?

Abstract
This study aimed to examine prospectively whether individual nighttime sleep characteristics at baseline (prior to shift work exposure) are related to parameters of daytime sleep after commencing shift work. A longitudinal field study was carried out with novice police officers of the Dutch police force. A total of 26 subjects were examined at baseline before they entered shift work and re-examined during follow-up sessions after four and twelve months of shift work exposure. Wrist actigraphy and sleep diaries were used to study nocturnal sleep at baseline and daytime sleep after night shifts during follow-up sessions. As outcome variables, estimated total sleep time, sleep efficiency, and subjective sleep quality were analyzed. Daytime total sleep time showed a 66 min decline during the first year of shift work exposure. Systematic inter-individual differences were observed for daytime total sleep time and subjective sleep quality (explaining 53% and 38% of the variance, respectively), suggesting potential predictability of these sleep parameters. Although no predictors were found for daytime total sleep time, the subjective quality of nighttime sleep before the onset of shift work predicted 40% of the variance in the subjective quality of daytime sleep after commencing shift work. Follow-up studies may reveal whether the subjective quality of baseline nighttime sleep also predicts long-term overall tolerance for shift work.

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Introduction
Sleep disturbances are among the most prominent problems related to shift work (Åkerstedt, 2003). In particular, during periods of night work, the duration as well as the structure of daytime sleep have been shown to be adversely affected by the shifted timing of the sleep period (Åkerstedt & Torsvall, 1981; Kerkhof & Lancel, 1991). Relative to nocturnal sleep, the duration of diurnal sleep appears to be reduced, with most of this sleep loss being stage two and REM sleep (Åkerstedt & Kecklund, 1991).

Inter-individual differences in sleep disturbances as a result of shift work are well recognized (Åkerstedt & Torsvall, 1981; Kerkhof & Lancel, 1991) and are believed to be related to long-term shift work tolerance (Costa, 1997). Limited research has focused on the predictors of these individual differences (Härmä, 1995). The literature on this topic is mainly cross-sectional and consequently is thought to be confounded by self-selection effects, known as the “healthy worker effect” (Knutsson & Åkerstedt, 1992). Longitudinal studies are better suited to provide insight into the relationship between predictor variables, measured before commencing shift work, and outcome variables, measured after commencing shift work.

Two previous studies measured sleep within the first years of shift work and related these measurements to baseline variables. In the first study (Vidaček et al., 1993), significant correlations were found between the peak time of the heart rate rhythm at baseline and overall subjective sleep quality after one year (r = -0.43, p < 0.01) and after three years (r = -0.23, p < 0.05) of shift work exposure. Subjects whose heart rate rhythm showed an early peak time before entering shift work showed better overall sleep quality after one and three years of shift work. The second study (Radoševic-Vidaček et al., 1995) showed a positive correlation between subjective sleep quality at baseline and subjective sleep quality in general (i.e., not specific for the timing of shifts) after 5.5 years of shift work exposure (r = 0.30, p < 0.01). These results suggest a possible relationship between individual characteristics measured at baseline and sleep quality during the subsequent period of shift work. However, in both studies, the effects of shift work exposure on sleep were only measured subjectively.

No longitudinal studies seem to have been done using both objective and subjective measures to assess individual sleep characteristics at baseline and after the accumulation of
shift work experience. Prospective studies of this kind are needed so that candidate predictors for daytime sleep parameters can be identified.

In the present study, subjects were measured both at baseline (before any exposure to shift work) and at two moments in time after commencing shift work. The follow-up sessions involved measurements of daytime sleep and took place four months and one year after the start of shift work exposure. Inter-individual differences were assessed in both objective and subjective measurements of daytime sleep during shift work. The goal of this study was to examine prospectively whether diurnal sleep parameters after commencing shift work could be predicted by individual sleep characteristics at baseline.

**Methods**

**Subjects**
As part of a larger study, N = 26 subjects (20–46 years old, mean age 28 years) participated in this longitudinal field study. Subjects were recruited at the police academy and volunteered to participate. They were physically and psychologically healthy without prior prolonged shift work experience. Subjects were novice police officers at the end of their training, before they began work in the Dutch police force. They were 18 males and 8 females, which reflects the gender distribution in the general working population of the police force. All subjects gave written informed consent, and the study was approved by the Ethical Committee of the University of Amsterdam. The study was conducted in accordance with guidelines described in this journal (Touitou et al., 2004).

**Experimental design**
The subjects were studied three times each. First, subjects were studied for baseline measurements during their last six months at the police academy. Follow-up sessions were conducted after the subjects had begun work in the Dutch police force. The first follow-up session took place after four months of shift work exposure (mean, 16 weeks; SD, 5 weeks). The second follow-up session took place after one year of shift work exposure (mean, 53 weeks; SD, 6 weeks).
Instrumentation

Sleep was characterized by means of sleep diaries and wrist actigraphy (baseline session: Gaehwiler Electronics, Hombrechtikon, Switzerland; follow-up sessions: Actiwatch, Cambridge Neurotechnology Ltd., Cambridge, UK). Sleep diaries were filled out upon awakening. Subjects recorded information about bedtimes, use of alcohol and sleeping pills, and subjective sleep quality (SSQ) as assessed with a five-point scale. Subjects were instructed to wear the actigraph on the non-dominant arm 24 h/day, except when showering or doing physical exercise. Using Actiwatch Sleep Analysis software (version 1.06, Cambridge Neurotechnology Ltd.), total sleep time (TST) and sleep efficiency (SE) were estimated from the actigraphic records on the basis of bedtime information taken from the sleep diaries. High agreement has been observed between polysomnography and wrist actigraphy for assessment of both night and daytime sleep periods (Reid & Dawson, 1999).

Baseline Measurements

Baseline measurements of nocturnal sleep were taken across four to five weekdays while subjects attended school at the police academy at fixed regular hours (08:00–16:00). For four subjects, baseline measurements were available for less than four week days, but no less than two days. This data loss was due to exclusion of sleep periods when subjects reported drinking more than three glasses of alcohol. Five candidate predictor variables were defined to describe essential individual, nocturnal sleep characteristics at baseline:

1. Average Total Sleep Time (TST), assessed by means of actigraphy.
2. Average Sleep Efficiency (SE), the ratio of TST to diary-assessed time in bed (TIB).
3. Average Subjective Sleep Quality (SSQ), as recorded in the sleep diary.
4. Average “bed in” time (BI), taken from the sleep diary.
5. Variability of BI times (VAR), the standard deviation across measurement days.

Follow-Up Measurements

During the follow-up sessions, subjects worked 38 h/week, including weekends. Their work schedules consisted of a mixture of three 8 h shifts: early (07:00–15:00 h), late (15:00–23:00 h), and night (23:00–07:00 h). The rotation speed and direction of the shifts varied.
across subjects. Daytime sleep measurements were taken after night shifts, which occurred from one to four times in each follow-up session (mean for session 1: 2.4 times; mean for session 2: 2.3 times).

The following three outcome variables were selected to characterize diurnal sleep:
1. Average TST, assessed by means of actigraphy.
2. Average SE, the ratio of TST to diary-assessed TIB.
3. Average SSQ, as recorded in the sleep diary.

**Analyses**

Predictors and outcome variables were examined by means of descriptive statistics. Paired-sample t-tests with Bonferroni correction were used to determine whether there was a significant difference between the average values for baseline and for each of the two follow-up sessions, as well as between the two follow-up sessions.

Systematic inter-individual differences in daytime sleep following night work were investigated by analyzing the sleep parameters across follow-up sessions 1 and 2. Outcome variables were entered into a mixed-model analysis of variance (ANOVA) with a fixed effect for time (repeated measure), covariates for age and gender, and a random effect for the intercept (SAS version 9.1; SAS Institute Inc., Cary, North Carolina, USA). Variance components analysis was performed to estimate the between-subjects variance ($\sigma^2_{bs}$) and the within-subjects variance ($\sigma^2_{ws}$), which were used to calculate the intraclass correlation coefficient or ICC (Van Dongen et al., 2004). Here, the ICC represents the fraction of the variance explained by systematic inter-individual differences after accounting for group-averaged trends over time as well as age and gender effects. The statistical significance of the systematic inter-individual differences was tested by means of a Wald Z test for $\sigma^2_{bs}$. The covariates were tested for significance by means of F tests.

Stepwise linear multiple regression analyses were carried out (SPSS version 12.0.1, SPSS Inc., Chicago, Illinois, USA) to assess predictive relationships between individual characteristics of nighttime sleep at baseline and daytime sleep at both follow-up sessions. The predictor set included the five individual sleep characteristics at baseline: TST, SE, SSQ, BI, and VAR. The regressions were carried out for each of the outcome variables
(TST, SE, and SSQ) averaged over the two follow-up sessions, provided that statistically
significant inter-individual differences were observed. Bonferroni corrections were applied
to adjust for multiple use of the predictor variables.

Results

Sleep Measurements
Nocturnal sleep characteristics at baseline are described in Table 1. The baseline TST
ranged from 5.1 to 8.5 h (mean 6.8 h), and bedtimes varied between 22:10 and 01:08 h,
indicating that pre-shift work sleep was positioned nocturnally in all subjects. The VAR
showed an average value of 31 min, expressing a moderate variability of bedtimes within
persons. Baseline SSQ scores exhibited a mean of 3.1, which reflected a neutral score on
the five-point rating scale.

Table 1. Descriptive statistics for baseline and follow-up measurements: total sleep time (TST), sleep
efficiency (SE), subjective sleep quality (SSQ), “bed in” time (BI) and variability of BI times (VAR).

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th></th>
<th>Follow-up 1</th>
<th></th>
<th>Follow-up 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
<td>Range</td>
<td>Mean (SD)</td>
<td>Range</td>
</tr>
<tr>
<td>TST (min)</td>
<td>409 (49)</td>
<td>306-510</td>
<td>381 (61)</td>
<td>287-511</td>
<td>343 (66)</td>
<td>222-506</td>
</tr>
<tr>
<td>SE (%)</td>
<td>87.4 (4.2)</td>
<td>75.6-92.5</td>
<td>87.1 (3.7)</td>
<td>79.7-93.3</td>
<td>84.4 (6.9)</td>
<td>69.9-93.4</td>
</tr>
<tr>
<td>SSQ a</td>
<td>3.1 (0.8)</td>
<td>1.4-5.0</td>
<td>3.5 (0.7)</td>
<td>2.0-5.0</td>
<td>3.4 (0.9)</td>
<td>1.3-5.0</td>
</tr>
<tr>
<td>BI (h)</td>
<td>23:20 (0:43)</td>
<td>22:10-01:08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VAR (min)</td>
<td>31.1 (14.2)</td>
<td>9.0-65.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a SSQ ranged from 1 to 5, with higher values indicating better subjective sleep quality.

Daytime sleep characteristics for the follow-up sessions are presented in Table 1 as well.
Average TST was reduced relative to nocturnal baseline sleep, with an average of 66 min.
Paired samples t tests revealed that this effect constituted a trend for the first follow-up
session ($t_{25} = 1.90, p = 0.069$) and was statistically significant for the second follow-up
Inter-Individual Differences

Table 2 shows the results of the mixed-model ANOVAs for the assessment of inter-individual differences in daytime sleep characteristics after the commencement of shift work. Systematic inter-individual differences were found for TST and SSQ (see Table 2), suggesting that these sleep characteristics could be predictable. For TST, as much as 53% of the variance was explained, and for SSQ, 38% of the variance was explained by systematic variability among subjects.

In agreement with the results of the paired-samples t tests, there was a significant time effect for TST (F_{1,25} = 9.83, p = 0.004); TST was reduced in follow-up session 2 relative to session 1. The covariate for age was significant for SSQ (F_{1,25} = 4.23, p = 0.050); older subjects gave higher ratings of sleep quality.

<table>
<thead>
<tr>
<th></th>
<th>σ^2_{bs}</th>
<th>σ^2_{ws}</th>
<th>ICC</th>
<th>Z</th>
<th>P</th>
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</thead>
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<tr>
<td>TST</td>
<td>0.59</td>
<td>0.53</td>
<td>0.53</td>
<td>2.23</td>
<td>0.01</td>
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<tr>
<td>SE</td>
<td>5.95</td>
<td>25.87</td>
<td>0.19</td>
<td>0.89</td>
<td>0.19</td>
</tr>
<tr>
<td>SSQ</td>
<td>0.23</td>
<td>0.37</td>
<td>0.38</td>
<td>1.75</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Abbreviations: σ^2_{bs} = between-subjects variance; σ^2_{ws} = within-subjects variance; ICC = intraclass correlation coefficient; Z = Wald Z test for the between-subjects variance; TST = total sleep time; SE = sleep efficiency; SSQ = subjective sleep quality.
Figure 1. Time course (means and standard errors) for total sleep time (TST), sleep efficiency (SE) and subjective sleep quality (SSQ). SSQ ranged from 1 to 5, with higher values indicating better subjective sleep quality.
Stepwise Multiple Regression Analyses
The significant inter-individual differences in daytime TST and SSQ prompted an examination of candidate baseline predictors for these variables. Thus, stepwise multiple regression analyses were performed for both TST and SSQ, as averaged over the two follow-up sessions, using the set of candidate predictors consisting of the baseline TST, SE, SSQ, BI, and VAR. After Bonferroni correction, no baseline predictors were significantly related to subject-specific daytime TST. However, the baseline nocturnal SSQ was a significant predictor of subject-specific daytime SSQ following shift work (β = 0.635, p < 0.001). This predictor explained 40% of the variance.

Discussion
The results of this prospective field study of beginning shift workers included the following significant findings:

1. total sleep time showed a decline for daytime sleep during the first year of shift work exposure;
2. daytime sleep, repeatedly measured during shift work, exhibited systematic inter-individual differences, suggesting predictability; and
3. a significant relationship was found between subjective quality of nighttime sleep at baseline and subjective quality of daytime sleep after commencing shift work.

Across the first year of shift work exposure, daytime total sleep time was progressively reduced (Figure 1, top panel), reaching a duration that was 66 min shorter than nocturnal sleep measured at baseline. This result provides objective confirmation of the self-reported decrease in sleep duration over the course of 5.5 years of shift work exposure as documented in the study of Radošević-Vidaček et al. (1995). The reduction of total sleep time in the present study may be attributed to the circadian misalignment of sleeping during the day, when the circadian drive for wakefulness is high. In addition, environmental conditions (e.g., light and noise) during the day are commonly unfavorable for sleep (Novak & Auvil-Novak, 1996). For a review of these issues, see Monk (2005).

Interestingly, sleep efficiency showed only a small but non-significant decline relative to baseline during the first year of shift work exposure (Figure 1, middle panel). Changes in
the characteristics of day versus nighttime sleep as well as changes in bedtime behavior may have contributed to the relatively stable values of sleep efficiency. Due to increased sleep pressure from prior sleep loss during shift work, a compensatory reduction in the onset latency of daytime sleep may have taken place (Kerkhof & Lancel, 1991). This would reduce the need to spend time in bed, thereby mitigating the reduction in sleep efficiency from diminished total sleep time. A further reduction in time spent in bed may have occurred due to competing social factors (Parkes, 1994).

Compared to the subjective quality of baseline nocturnal sleep, the subjective quality of diurnal sleep remained essentially the same (Figure 1, bottom panel). This observation is consistent with the study of Radošević-Vidaček et al. (1995), who found no change in overall subjective sleep quality over the first 5.5 years of shift work exposure. This counterintuitive result might be explained as following from a gradual shift of the reference point for the subjective evaluation of sleep (i.e., a form of subjective habituation to sleeping during the day).

In spite of the typically large state-dependent variability (noise) in the data of field studies like this one, there was subject-specific consistency in the characteristics of daytime sleep following shift work. This was substantiated by the statistically significant ICC values for total sleep time and subjective sleep quality (Table 2), which demonstrated that inter-individual differences in these variables were relatively stable over time. Previous shift work studies attempted to quantify the person-specific consistency in sleep by means of correlation coefficients. Although this approach is not statistically optimal (Van Dongen et al., 2004), it was used by Radošević-Vidaček et al. (1995) to point out that subjective sleep duration was stable over measurements taken at 1.5, 3.5, and 5.5 years of shift work, across early, late, and night shifts, as well as days off. Åkerstedt and Kecklund (1991) also observed within-subject stability of subjective sleep quality, as well as polysomnographically assessed sleep stages, for night and daytime sleep in experienced shift workers recorded twice with a two-year interval of time.

The presence of stable inter-individual differences in daytime sleep characteristics suggests that the sleep of individual shift workers may be predictable. However, no candidate predictors for actigraphically measured total time of daytime sleep were found. This study is ongoing, with an additional follow-up session being scheduled. It is likely that the
additional data thus acquired will increase statistical power to detect baseline predictor variables.

In the current analyses, significant predictors were already found for the subjective quality of daytime sleep within the first year of shift work. First, age was a significant covariate for daytime subjective sleep quality. In the age range of 20–46 years, the older shift workers reported better sleep quality. This result is contradicted by adverse age-related effects on shift work tolerance found previously (Åkerstedt & Torsvall, 1981; Parkes, 1994). The subjects in the present study were relatively young, with only three subjects older than 40 years of age. This, combined with the relatively short period of shift work exposure, may have protected them (as of yet) from the increasing sensitivity to sleep/wake disruptions associated with older age (Foret et al., 1981).

Second, in the present prospective study, there was a positive relationship between the subjective quality of baseline nighttime sleep and the subjective quality of daytime sleep during shift work. This result is in line with the observation by Radošević-Vidaček et al. (1995) of a positive correlation between subjective sleep quality at baseline and after 5.5 years of shift work exposure (regardless of the timing of the shifts). It suggests that under common conditions, shift workers’ subjective experience of sleep quality may be predominantly related to characteristics other than the biology of sleep and circadian rhythms. It is possible that personality characteristics are involved, as has been considered in earlier shift work studies. For instance, Parkes (1994, 2002) showed that subjects who scored high on neuroticism consistently reported poorer sleep quality compared to those who scored low on neuroticism. She stated that the “negative perception” associated with high neuroticism may account for these findings. Such observations support the notion that the predictive value of subjective sleep quality may have a more psychological rather than biological nature.

In conclusion, this study presented data from the first part of an ongoing longitudinal field study, in which baseline measurements (before commencing shift work) are being followed by three repeated measures during the first two years of shift work experience. This prospective, within-subjects research design avoids the bias from the “healthy worker effect” of self-selection in shift work populations.
The current study provides a platform for the identification of person-specific predictors for various aspects of shift work tolerance, such as sleep/wake physiology, subjective health, and cognitive performance. The first results, focusing on sleep, indicate the predictive value of the subjective quality of baseline nocturnal sleep for the subjective quality of daytime sleep during the first year of shift work exposure. Subjective sleep quality may not be interpreted as a surrogate measure for sleep physiology, and predictors for objective daytime sleep parameters remained elusive in this study. Even so, it would be reasonable to suspect that people’s subjective experience of daytime sleeping, more so than the underlying physiology, determines their behavioral responses to shift work. Individuals perceiving their daytime sleep as poor may engage in unhealthy compensatory behavior, such as excessive caffeine intake or overeating (Novak & Auvil-Novak, 1996; Waterhouse et al., 2003). The recent surge in literature about the bidirectional interactions between sleep, metabolism, and health would seem to elicit such a conjecture (Al-Naimi et al., 2004; Van Cauter, 2005). The authors’ forthcoming measurements of the health consequences of commencing shift work after one and two years on the job will shed light on this issue.