Individual differences in shift work tolerance
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“Some must watch, while some must sleep”

Shakespeare
(Hamlet)
Chapter 6

Inter-individual differences in sleep response to shift work in novice police officers – a prospective study

Abstract
The aim of this longitudinal study on novice police officers was to investigate inter-individual differences in sleep response to shift work and to identify potential baseline predictors thereof. A total of 42 subjects was assessed at baseline, prior to commencing shift work. They were re-assessed during three follow-up sessions within the first two years of shift work exposure after approximately 4, 12 and 20 months of rotating shift work. Wrist actigraphy and sleep logs were used to investigate nocturnal sleep at baseline and daytime sleep after night shifts during the follow-up sessions. Actigraphically estimated total sleep time and subjective sleep quality were analyzed as outcome variables, using mixed-effects analysis of variance. Systematic inter-individual differences in the overall response to shift work were observed. In this sample, flexibility of sleeping habits and gender were found to be significant predictors of daytime total sleep time in the first 2 years of shift work exposure. Flexibility of sleeping habits and subjective quality of nighttime sleep prior to shift work were significant predictors of subjective quality of daytime sleep. These results suggest that it may be possible to detect and even predict sleep deficiencies in response to shift work early on, which could be a basis for the development of individualized interventions to improve shift work tolerance.

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Introduction

Sleep-wake disturbances are among the most pertinent and challenging problems of shift work (Åkerstedt, 2003; Åkerstedt & Wright, 2009; Vila, 2006). Both the duration and the structure of sleep are affected by shifted timing of sleep periods (Åkerstedt et al., 1991; Kerkhof & Lancel, 1991). In the short term, shift workers suffer from insomnia and/or excessive sleepiness, performance decrements, and mood swings (Drake et al., 2004; Rajaratnam et al., 2013). In the long term, workers may develop shift work disorder and a variety of other physical and mental health-related problems (Roth, 2012; Wright et al., 2013). Higher incidence rates of metabolic syndrome, cardiovascular disease, mood disorders and cancer among shift workers have been well documented (Puttonen et al., 2010; Vogel et al., 2012; Wang et al., 2011). Sleep problems resulting from circadian misalignment and associated deficits in performance and health are key determinants of long-term shift work intolerance (Costa, 2003; Morris et al., 2012b; Puttonen et al., 2010; Rajaratnam et al., 2013; Wang et al., 2011). Even in retirement, shift workers report more sleep problems than day workers (Monk et al., 2013).

There is substantial inter-individual variability in the development and severity of shift work intolerance (Härmä, 1993; Saksvik et al., 2011). It would be beneficial in terms of worker productivity, health and well-being if it were possible to recognize symptoms of shift work intolerance early on in those who are most vulnerable. Several studies have been conducted to identify factors predicting shift work (in)tolerance; for a recent review see Saksvik et al. (2011). Age and gender have been suggested as candidate predictors of inter-individual differences in shift work tolerance (Hakola et al., 1996; Härmä & Kandolin, 2001), although conclusive evidence has yet to be presented. A variety of other potential predictors, such as demographics, personality, and social environments, have also been investigated (Saksvik et al., 2011; Storemark et al., 2013). Results have been mixed and inconclusive.

Given the central role of sleep deficiencies in shift work, it has been proposed that person-specific characteristics of circadian rhythms and sleep/wake regulation may be involved in inter-individual differences in shift work tolerance. Vulnerability to sleep loss, circadian phase position (chronotype), and flexibility of sleep timing (natural ability to sleep and work at unusual times of day) have been suggested as predictors (Iskra-Golec, 1993;
Kerkhof, 1985; Lammers-van der Holst et al., 2006; Van Dongen, 2006; Van Dongen & Belenky, 2009).

A complication in attempts to identify predictors of shift work tolerance is that it is often impossible to distinguish cause from consequence. Most studies are retrospective, cross-sectional, and/or based on a selection of experienced shift workers, which causes a confound known as the ‘healthy worker’ selection effect (Knutsson & Åkerstedt, 1992). To avoid this confound, longitudinal field studies with baseline measures taken prior to commencing shift work are needed.

This investigation involved a longitudinal study of novice police officers. Baseline measures were taken before they commenced shift work, and three follow-up measures were taken within the first 2 years of shift work exposure. We examined inter-individual differences in sleep responses at this early stage of shift work, and sought to identify unbiased baseline predictors.

**Methods**

**Subjects**

In this longitudinal study, 42 novice police officers (30 males, 12 females; ages 20–46 y, mean age 27 y) from two cohorts (classes) of the Dutch police force academy participated. Initially, 46 police officers volunteered for the study, but four of them were not compliant with study procedures, leaving a sample size of N = 42. At the start of the study, the subjects were near the end of their 4-year education and training period. They were fit for duty by the criteria of the Dutch police force, and reported to be healthy with no psychiatric records. They denied any prolonged prior shift work experience. All subjects gave written informed consent. The study was approved by the Ethical Committee of the University of Amsterdam, and was conducted in accordance with international ethical standards (Portaluppi et al., 2010).

**Experimental design**

Subjects were tracked over a period of two years, during which they were tested four times. In the initial assessment (T0), baseline measurements were taken while subjects were still at
the police academy, working daytime schedules. During three follow-up assessments (T1–T3), one cohort (N = 18) worked full time in rotating shift work throughout, and the other cohort (N = 24) worked full time in rotating shift work with an 8-week period of daytime duty between T1 and T2. The first, second and third follow-up assessments took place at 16 ± 4 weeks, 54 ± 5 weeks and 82 ± 6 weeks (mean ± SD) after commencing shift work, respectively.

The nominal shift work schedule involved three 8-hour shifts, i.e., morning shifts (07:00-15:00), evening shifts (15:00-23:00) and night shifts (23:00-07:00), rotating in forward direction. Extended shifts (≥ 9 hours) occurred on 41% of all recorded workdays. Schedules were also characterized by a high degree of ad hoc scheduling, characteristic of the field work of police officers.

**Sleep measurements**

Sleep characteristics were assessed by means of sleep logs and wrist actigraphs. Baseline measurements spanned nighttime sleep periods of 4 to 5 consecutive week days (mean and SD: T0: 4.5 ± 0.8). Follow-up assessments involved an average of 2.5 (T1: 2.4 ± 0.8, T2: 2.4 ± 0.8, T3: 2.6 ± 0.8) consecutive night shifts and subsequent daytime sleep periods. Preliminary results of T1 and T2 measurements in a subgroup of 26 subjects were published previously (Lammers-van der Holst et al., 2006).

Objective and subjective (self-report) characteristics of nighttime sleep (baseline assessment) and daytime sleep (follow-up assessments) were measured. Subjects filled out a sleep log upon awakening. They recorded bedtimes, use of alcohol and sleep medication, and subjective sleep quality (SSQ) on a 5-point rating scale.

During the baseline period (T0), subjects wore a wrist actigraph of Gaehwiler Electronics (Hombrechtikon, Switzerland). During the follow-up periods (T1–T3), they wore the smaller and more convenient Actiwatch of Cambridge Neurotechnology Ltd. (Cambridge, UK). Actigraphs were worn on the non-dominant arm, 24 hours per day, except when subjects were in contact with water or doing vigorous physical exercise.

Total sleep time (TST) was extracted from the data provided by both actigraph types using the Actiwatch Sleep Analysis software (version 1.06, Cambridge Neurotechnology Ltd.),
guided by the information recorded in the sleep logs. Sleep periods preceded by consumption of 4 or more alcoholic drinks were excluded from the analyses. TST and SSQ served as the primary outcome variables in this study.

**Predictor variables**

At baseline, background information about personal, demographic and circadian characteristics was assessed by means of a computerized questionnaire. For each primary outcome variable, six candidate predictors were assessed: baseline value of the primary outcome variable (TST/SSQ), age, gender, morningness, flexibility of sleeping habits, and vigoroussness (i.e., the ability to overcome drowsiness). Morningness was tested with a validated 7-item morningness-eveningness questionnaire, VOA (range 7-31) (Kerkhof, 1984). Sleep flexibility (range 6-30) and vigorousness (range 4-20) were derived from subscales of a Dutch translation of the Circadian Type Questionnaire (CTQ) (Folkard et al., 1979), with a 5-point rating scale (10 items).

**Statistical analyses**

Analyses were performed using SAS version 9.3 (SAS Institute Inc., Cary, NC, USA). Out of the 42 subjects, seventeen subjects had some missing data. Our analysis approach was not predicated on having complete data, so these subjects’ data were included in the analyses.

The primary outcome variables (TST and SSQ) and the candidate predictors were first examined by means of descriptive statistics. The change in the primary outcome variables from T0 to T1–T3 was investigated using mixed-effects analysis of variance (ANOVA) with fixed effects for time point (T0–T3), cohort, and their interaction, and a random effect over subjects on the intercept (Van Dongen et al., 2004). A planned contrast was implemented in order to compare T0 to T1–T3.

The TST and SSQ data of the follow-up assessments were then analyzed with mixed-effects ANOVA with fixed effects for time point (T1–T3) and a random effect over subjects on the intercept. Inter-individual differences in overall responses to shift work sustained over T1–T3 were assessed using the intraclass correlation coefficient (ICC), defined as the between-
subjects variance divided by the sum of the between- and within-subjects variances (Van Dongen et al., 2004).

Next, the TST and SSQ data of the follow-up assessments were converted to difference scores (T2 minus T1, T3 minus T2). The difference scores were analyzed with mixed-effects ANOVA with fixed effects for time point (T2, T3), cohort, and their interaction, and a random effect over subjects on the intercept. Systematic inter-individual differences in the rate of change over time points were assessed using the ICC.

If inter-individual differences in overall responses to shift work or in the rate of change over time points were found to be statistically significant, then the analyses were repeated with baseline TST or baseline SSQ included as covariate, both separately and in interaction with time point. These last analyses were repeated with each of the five remaining candidate predictors (age, gender, morningness, flexibility of sleeping habits, and vigoroussness), one by one, included as additional covariate, both separately and in interaction with time point. The statistical significance of each candidate predictor was assessed with a variance ratio test for nested models.

**Results**

Figure 1 shows the means and standard errors of TST and SSQ across the four measurement periods. For TST, there was a significant main effect of time point ($F_{3,95} = 8.54, p < 0.001$). The planned contrast comparing T0 to T1–T3 was significant ($F_{1,95} = 22.48, p < 0.001$), reflecting an overall reduction of 48 min of TST from before to after commencing shift work. For SSQ, there was no significant main effect of time point, but the planned contrast comparing T0 to T1–T3 was significant ($F_{1,87} = 4.80, p = 0.031$) reflecting an overall increase (improvement) of 0.26 points in the SSQ rating from before to after commencing shift work. Note the discrepancy between the change in sleep as measured objectively (reduced TST) versus subjectively (improved SSQ).

Systematic inter-individual differences were observed for TST (ICC = 0.44, $p = 0.002$) and SSQ (ICC = 0.41, $p = 0.007$) during the follow-up assessments after commencing shift work (T1–T3). For TST, 44% of the variance was explained by systematic inter-individual variability. Thus, up to 44% of the variance in TST during shift work exposure could be predictable by the police officers’ baseline characteristics. For SSQ, 41% of the variance
was explained by systematic inter-individual variability, and thus potentially predictable. There were no significant inter-individual differences in the rate of change from T1 to T3 in either TST or SSQ.

Figure 1. Time courses (means and standard errors) for total sleep time (TST; top) and subjective sleep quality (SSQ; bottom) over the baseline assessment (T0) and the follow-up assessments after commencing shift work (T1–T3). SSQ ratings range from 1 to 5, with higher values indicating better subjective sleep quality. Values TST: 401 (8), 365 (11), 346 (11), 343 (11); SSQ: 3.2 (0.1), 3.5, (0.1), 3.5 (0.1), 3.3 (0.2).
Candidate predictor analyses were based on a sample of $N = 39$, as baseline TST and SSQ values were missing in 3 police officers. Baseline TST (at T0) was not a significant predictor of inter-individual differences in daytime TST after commencing shift work (at T1–T3). However, baseline SSQ was a significant predictor of inter-individual differences in daytime SSQ after commencing shift work ($F_{6,49} = 3.48, p = 0.006$), with higher baseline SSQ predicting higher SSQ during the follow-up sessions.

Descriptive statistics and pairwise correlations of the remaining candidate predictors as measured at baseline are shown in Table 1. Age was correlated with gender – as a group, females ($23 \pm 3$ y) were younger than males ($28 \pm 8$ y). Vigorousness was related to both age and gender, where older age and being male were related to higher scores of vigorousness in our sample.

### Table 1. Descriptive statistics (means and standard deviations) and correlations of the person-specific characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Gender</th>
<th>Morningness</th>
<th>Flexibility</th>
<th>Vigorousness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>26.7 (7.5)</td>
<td>– 0.33*</td>
<td>0.02</td>
<td>0.00</td>
<td>0.45**</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>30/12</td>
<td>0.12</td>
<td>0.25</td>
<td>– 0.36*</td>
<td></td>
</tr>
<tr>
<td>Morningness (7-31)</td>
<td>19.1 (3.1)</td>
<td></td>
<td>– 0.05</td>
<td>– 0.28</td>
<td></td>
</tr>
<tr>
<td>Flexibility (6-30)</td>
<td>22.3 (3.5)</td>
<td></td>
<td></td>
<td>– 0.04</td>
<td></td>
</tr>
<tr>
<td>Vigorousness (4-20)</td>
<td>13.0 (2.4)</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

* $p < 0.05$, ** $p < 0.01$.

Gender ($F_{2,54} = 4.85, p = 0.012$) and flexibility of sleeping habits ($F_{2,54} = 4.21, p = 0.020$) were found to be significant predictors of daytime TST during shift work. Females exhibited greater TST during the follow-up sessions than males, and flexible types showed greater TST during the follow-up sessions than more rigid types. Flexibility of sleeping habits was a significant predictor of daytime SSQ during shift work as well ($F_{1,48} = 4.86, p = 0.032$), but flexible types showed slightly lower SSQ over the three follow-up sessions than more rigid types.
Discussion

In this prospective study, we investigated inter-individual variability in the objective and subjective sleep response to shift work and sought to identify potential baseline predictors. We studied a relatively small sample of a population uniquely suited for our purpose, novice police officers. In their occupational setting, police officers are in a high-stress environment and they frequently experience irregular and extended shifts (Vila, 2006; Zimmerman, 2012). In this study, 41% of recorded work days were 9 h or longer. Our sample consisted of relatively young police officers who were fit for duty by the criteria of the Dutch police force and scored low on morningness (i.e., high on eveningness). These characteristics might have worked to their advantage in terms of shift work tolerance (Kecklund et al., 2008).

We observed systematic inter-individual differences in TST after commencing shift work. Entry into shift work was associated with an overall reduction of daytime TST (by 48 min on average) as compared to nocturnal sleep prior to commencing shift work (Figure 1). Systematically reduced TST is important both operationally and clinically, as chronic sleep restriction is associated with degraded performance and safety and adverse health effects and decreased life expectancy (Cappuccio et al., 2011; Raslear et al., 2011).

We also observed systematic differences between subjects in the subjective quality of daytime sleep after commencing shift work. Counterintuitively, the SSQ of daytime sleep in shift work was slightly higher than the SSQ of nighttime sleep at baseline (Figure 1). The dissociation between changes in objective sleep duration and in subjective sleep quality may involve a relative change of subjective reference point rather than an absolute improvement in SSQ.

The presence of stable inter-individual differences in the overall sleep response to shift work (TST and SSQ) is consistent with our preliminary results reported previously (Lammers-van der Holst et al., 2006). A large amount (> 40%) of the variance of TST and SSQ was explained by systematic inter-individual variability. This suggests that the sleep response to shift work may be predictable, and person-specific characteristics may be examined for their potential as predictors. We found that the SSQ of nighttime sleep prior to shift work was a significant predictor of the SSQ of daytime sleep after commencing
shift work, which is consistent with results of a previous study (Radošević-Vidaček et al., 1995).

Our finding that flexibility of sleeping habits predicted both the TST and the SSQ response to shift work is congruent, to some extent, with results of a prospective survey of novice nurses (West et al., 2007). This study reported a negative correlation between flexibility of sleeping habits and subjective sleep disturbance associated with night shift after 6 months of shift work; however, this relationship disappeared after 12 months of shift work (West et al., 2007). Our finding that females (which constituted only 28.6% of the sample) showed greater TST after night shifts than males would seem to contradict the typical finding that female gender predisposes to shift work intolerance (Saksvik et al., 2011). In our sample, however, females as a group were younger (23 ± 3 y) than males (28 ± 8 y). The female shift workers in our sample may not have had domestic duties and/or children at home yet, which is believed to be a significant contributor to shift work intolerance in shift workers in general (Monk, 1988).

Enduring sleep deficiencies are considered to be a major component of shift work intolerance (Reinberg & Ashkenazi, 2008). Early detection of sleep deficiencies is an essential first step in the deployment of targeted treatments and countermeasures in order to decrease the risks of sleepiness-related accidents and help prevent long-term adverse health outcomes. The inter-individual variability in the sleep response to commencing shift work documented in this paper underlines the importance of an individualized approach to this issue (Van Dongen, 2006). Participation of the individual shift worker in scheduling working times, for instance through self-rostering, offers one potential strategy for mitigating sleep problems and improving shift work tolerance (Albertsen et al., 2014).