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Differential 24-h variations of alertness and subjective tension in process controllers: investigation of a relationship with body temperature and heart rate

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ABSTRACT

The effects of shift and time-on-shift on alertness and perceived tension, and related physiological variables were investigated in satellite controllers working a rapid forward rotating 3-shift system. In controlled laboratory conditions subjective tension and heart rate have been reported to display circadian variations and a marked sensitivity to external factors. We examined whether in real-job conditions circadian variations were masked for these particular variables, unlike for alertness and body temperature which have been repeatedly shown to display circadian variations in these conditions. This hypothesis was tested in a repeated measures design by collecting alertness and tension self-reports, and recording operators' sublingual temperature on 3 occasions on each shift, and heart rate continuously throughout shifts. Alertness and body temperature varied according to a typical diurnal trend, subjective tension was only enhanced on the initial recording of each shift (compared to the remaining), while heart rate displayed an intermediary trend. Intra-subjects correlations revealed a positive relationship between alertness, oral temperature and heart rate, while no such relationship was found for subjective tension. These results support the hypothesis of a close dependence for alertness and temperature, and to a lesser extent for heart rate, on endogenous mechanisms in this job-situation. In addition, some situation-specific factors, such as job-demand, would affect subjective tension and partially mask the circadian variations in heart rate.

Keywords: shift-work, time on shift, alertness, subjective tension, heart rate, body temperature.

INTRODUCTION

Several authors have suggested that there are two distinct forms of arousal, labelled tense and energetic. Energetic arousal (or alertness) is a continuum ranging from tired to energetic which describes the subject's alertness state. Tense arousal (or mood) is on a continuum ranging from calmness to anxiety, which describes a variety of emotions (i.e. anxiety) and stress reactions in response to external stressors (Dickman, 2002; Koscec & Radosevic-Vidacek, 2004; Matthews et al., 1990; Thayer, 1978). While time-of-day effects have been intensively studied for alertness, there have been few investigations of mood, and in particular negative mood in a chronobiological context, despite obvious consequences on performance, and hence work safety and security.

Field studies of alertness indicate a similar trend for this dimension in shift-work conditions and in controlled laboratory conditions, with a maximum of alertness on the late afternoon (Folkard & Tucker, 2003; Kecklund et al., 1997; Knauth, 1996; Rosa, 1995; Tucker et al., 1998). A close relationship has been reported between self-reported alertness and core body temperature, a measure that has been directly linked to metabolism (Colquhoun et al., 1968; Edwards et al., 2007; Koscec & Radosevic-Vidacek, 2004; Owens et al., 2000; Wright et al., 2002). These findings are generally interpreted as indicating a strong dependency of alertness on endogenous mechanisms that underlie circadian rhythms, i.e. a circadian system inducing a nocturnal trough of most physiological and psychological variables and a homeostatic system reflecting the fatigue accumulated across waking hours (Borbély, 1982; McCarley & Massaquoi, 1986; Achermann & Borbély, 1994; Folkard & Ackerstedt, 1992). In performing shift work many individuals experience chronic sleep deprivation and increased fatigue, that aggravate the nocturnal decline in alertness and performance (Akerstedt, 1991, 2007; Dinges et al., 1996; Glazner, 1991; Knauth, 1996; Lammers-van der Holst et al., 2006; Van Dongen, 2006) and increase accident risk (Costa et al., 2006; Folkard & Tucker, 2003; Folkard et al., 2006; Tucker et al., 2006). In addition, peak-time alertness depends to some extent on shift-scheduling features, such as the number of successive night-shifts (Folkard & Tucker, 2003), shift-duration (Knauth, 1996; Mélan et al., 2007), and night-to-morning shift hand-over time (Tucker et al., 1998). Despite chronic fatigue and differences between shift-scheduling systems, the general shape of the alertness curve remains day-oriented, at least in shift-workers working rapid rotating shift systems.

Around-the-clock variations of perceived tension or other negative mood measures were less extensively studied, and the situation appears to be less clear. Subjective tension was shown to vary with time of day in some laboratory studies (Thayer, 1978; Koscec & Radosevic-Vidacek, 2004), but not in others (Monk et al., 1985; Owens et al., 2000). Likewise, air traffic controllers' tension ratings have been found to be comparable on night- and day-work (Luna et al., 1997), or displaying a typical circadian trend (Galy et al., 2006; Mélan et al., 2007). Inconsistency amongst the findings has been attributed to a marked sensitivity of mood measures to a number of external influences, including sleep timing and duration, task demands, meal times (Folkard, 1990; Owens et al., 2000), and shift-work conditions. More specifically, negative mood variations across the 24-h day have been found in shift-workers but not in non shift-workers (Prizmic et al., 1995). In addition, early compared to late morning-shift start was associated with higher apprehension stress (Kecklund et al., 1997). We recently reported higher self-rated tension in air traffic controllers who were on duty for six hours or more rather than for four hours or less (Mélan et al., 2007).

Taken together, the literature data raise the possibility that negative mood shows a lesser dependence on the endogenous mechanisms underlying circadian variations than other psychological measures, in particular alertness. Thayer (1978, 1989) proposed that in every-day life subjective tension would display a circadian trend, while in tension-inducing conditions external influences would mask the circadian trend. Such a masking effect has been explained by fragmented sleep and a de-stimulating environment in controlled laboratory conditions (Eriksen et al., 2006; Koscec & Radosevic-Vidacek, 2004) and by time on duty and task-related factors, in particular traffic intensity in real air traffic control conditions (Mélan et al., 2007). Real-job performance variations over the 24-h day have also been reported to be critically influenced by task-specific factors, as indicated by a masking affect on the nocturnal performance drop by workload, incentives, and motivation (Andorre-Gruet & Queinnec, 1998; Blake, 1971; Horne & Pettitt, 1985). Likewise, in real and simulated air traffic conditions, unexpected events and traffic intensity increases enhance controllers' subjective workload and heart rate, without affecting control operations (Rose et al., 1982; Brookings et al., 1996; Averty et al., 2004).

The aim of this study was to test the hypothesis of a differential sensitivity of alertness and tension to endogenous versus exogenous influences in satellite controllers, and to compare the 24-h variations of psychological measures with those of two particular physiological measures, body temperature and heart rate. Contrary to what is known about body temperature and alertness, little is known about heart rate and tension variations in shift-work conditions, though there is some evidence of a similar response profile for heart rate and tension. On the one hand, heart rate indicates circadian variations in controlled laboratory conditions (Wojtczak-Jaroszowa & Banaszkievicz, 1974; Furlan et al., 1990; for a review, Guo & Stein, 2003), even in the absence of physical activity (Yamasaki et al., 1996), and in total sleep deprivation conditions (Miro et al., 2002). On the other hand, a heart rate activation effect was reported for various exogenous factors, including general work conditions such as external temperature or shift-work (Khaleque, 1984; Van Eekelen et al., 2004), and task-specific factors like workload (Averty et al., 2004; Brookings et al., 1996; Rose et al., 1982) and cognitive load (Backs & Seljos, 1994; Carroll et al., 1986; Fairclough & Kim, 2004). Subjective tension ratings have also been proposed to be sensitive to external factors, at least in tension-inducing conditions (Mélan et al., 2007; Thayer, 1978, 1989; Koscec & Radosevic-Vidacek, 2004). Such conditions may be encountered during satellite control, given for instance the high workload involved in shift-commencement during continuous supervision of a dynamic process (Hoc & Amalberti, 1995), and the ecologic and economic consequences of a maintenance error. In light of these considerations, heart rate was seen as an objective marker of perceived tension in the present study. Likewise, body temperature, the most common indicator of circadian variation in physiological activation, was considered as an objective measure of operators' alertness state.

On three occasions during each shift, i.e. one hour following shift-start, in the middle of the shift and one hour before shift-end, the operators completed Thayer's (1978) check-list and measured their oral temperature, while heart rate was recorded continuously throughout shifts. The repeated-measures design enabled a two-factor analysis of the effects of shift and recording-time on shift to be conducted. As operators worked a rapid forward rotating 3-shift system, we expected to find a typical circadian trend for body temperature and for alertness (Folkard, 1990; Owens et al, 2000; Folkard & Tucker, 2003; Wright et al., 2002), evidenced by an interaction between the two factors under investigation. Furthermore, if heart rate and tension were indeed sensitive to the same, ill-defined, external factors in this job-situation, rather than to circadian influences, we should observe an effect of recording-time on shift for both measures. In addition, a positive relationship was expected between oral temperature and alertness scores on one the hand, and between heart rate and tension scores on the other.

SUBJECTS AND METHODS

Subjects

The study was carried out with 14 volunteer satellite controllers (11 males and 3 females), living in the south-west of France, aged 36.7 years (range 23 to 59 years) and with an average of 3.75 years seniority in the control centre (range 2 to 12 years). Their job entails the supervision of an automated continuous process which maintains a satellite in its orbit and to check whether information is correctly transmitted. The 10-day work cycle starts with 2 mornings, followed by 2 afternoons, 1 day off, 2 nights, and terminates following 3 days off. Work is scheduled according to a continuous 3-shift system, with shifts lasting 8+/-1h and starting at 07:00, 14:00 and 22:00 respectively.

Prior to the study they were also asked to complete Horne and Östberg's (1977) questionnaire. The results indicated that no participant displayed extreme morningness or eveningness. The study protocol and data analysis respected the identity and privacy of the workers (Touitou et al., 2006).

Material and Methods

Subjective and physiological measures (except for heart rate) were recorded on three occasions on each shift, respectively one hour after shift-start, in the middle of the shift, and one hour before shift-end at the following times: 08:00, 10:30, and 13:00 of the first morning-shift; on 15:00, 18:00 and 21:00 of the first afternoon-shift, and on 22:00, 02:30, and 6:00 of the first night-shift.

Subjective measures: On each of the 9 recording times participants completed the French paper-and-pencil version of Thayer's activation-deactivation adjective checklist (Thayer, 1978), by quoting, for each of 20 listed adjectives, one of the following responses "not at all", "don't know", "little", "much". The responses have an assigned weight respectively of 1, 2, 3 and 4. However, two adjectives have a negative weight assigned to them. The responses are compiled into four factors, general activation (GA), deactivation sleep (DS), high activation (HA), and general deactivation (GD). Subject's energetic alertness was assessed by the ratio GA/DS, reported to be a reliable index of alertness in shift-work conditions (Galy et al., 2006; Mélan et al., 2007) and their negative mood scores by HA, a factor "associated with subjective tension" (Thayer, 1978, p.5).

Physiological measures: On each of the 9 recording times oral temperature was measured sublingually, for 2 minutes, by means of an electronic thermometer (Viosiomed ThermoFluoKF-201™). During measurement, subjects sat comfortably in an armchair. They were instructed not to consume food or beverages during the 15 minutes prior to each measurement to preserve normal mouth temperature. Heart rate (HR) was recorded continuously throughout each shift with an ambulatory heart rate monitor (Polar S610i™), comprised of a transmitter worn around the chest and a receiver worn on the non-dominant wrist. The receiver stores the HR values before transferring them by infrared communication to a computer where they are subsequently analyzed using the Polar precision software.

Statistics

The subjective and physiological variables were analysed using 2-way ANOVAs testing for the effects of recording-time on shift (with repeated measures: 1 h following shift-start, middle of the shift, 1 h before shift-end), and shift (morning-shift, afternoon-shift, night-shift). Post hoc analyses were conducted using Scheffe's test. To enable a similar 2-way ANOVA for heart rate, recorded continuously, we computed, for each subject, the median number of heart beats per minute recorded during 15 min prior to and following each of the three recording times on each shift (i.e. 1 h following shift-start, in the middle of the shift, 1 h prior shift-end). Pearson's correlation was used to test whether any two measures were correlated with one another. Correlations were computed within participants (n=9 for each person separately), by using the 9 time-of-day values of two measures. The 14 r values were tested against the null hypothesis by using a 1-sample t test.

RESULTS

Figure 1 represents the mean data relating to on-shift alertness with a maximum at 15:00 and a minimum during early morning hours. A 2-way ANOVA with repeated measures revealed significant effects for shift ($F(2,117) = 35.86$, $p < 10^{-4}$), recording on shift ($F(2,117) = 3.54$, $p < .04$), and a significant interaction between these factors ($F(4,117) = 4.33$, $p < .003$). Post-hoc analysis revealed that operators rated alertness at a lower level on the last two recordings of the night-shift compared to all other recordings (in each case, $p < .01$), except for the first recording on the night-shift.

[Insert Figure 1 about here]

Inspection of Figure 2, representing operators' mean subjective tension on the same 9 recordings across the 24-h day, shows higher values for the first recording compared to the remaining recordings on each shift. A 2-way ANOVA revealed a significant main effect of recording on shift ($F(2,117) = 5.85$, $p< .01$), but no significant effect of shift or interaction between the two factors. Post-hoc tests confirmed the impression gained from the figure, as tense arousal was significantly enhanced on the first recording compared to the second ($p < .01$), and the third recording ($p < .05$) on the shift. It is noteworthy that 7 out of the 14 subjects quoted the same responses throughout recordings for this measure.

[Insert Figure 2 about here]

Mean sublingual temperature measures obtained on each of the nine recordings (Figure 1) resulted in a classic diurnal trend, with a maximum between 15:00 and 21:00, followed by a sharp decrease on early morning hours with a minimum at 06:00. Statistical analysis revealed, similar to alertness, a significant effect of shift ($F(2, 117) = 13.139$, $p < .001$), phase of shift ($F(2,117) = 4.956$, $p < .01$), and a significant interaction between the two factors ($F(4,117) = 18.172$, $p < .001$). Post-hoc tests indicated a lower oral temperature on the last recording of the night-shift compared to the recordings performed on the morning- and afternoon-shift ($p <.001$).

[Insert Figure 3 and Table 1 about here]

Figure 3, representing subjects' median heart rate per 5-min period, indicates overall higher heart rate values on shift-start than on the remaining time of the shift. On the morning and afternoon shifts, the operators' median heart rate decreased earlier and more rapidly than on the night-shift. A 2-way ANOVA of the median data collected around each of the 9 recording times (see statistics in the METHOD section; Table 1), revealed a significant effect of recording time on shift ($F(2,117) = 16.72$, $p < .001$), and an interaction of this factor and shift ($F(4,117) = 3.96$, $p < .001$). The significant main effect resulted from a higher median heart rate on the first recording than on the second and third recordings for the shift (in each case, $p < .001$). The interaction resulted from lower heart rates when ending the night-shift (06:00), rather than starting either shift (08:00, $p < .05$; 15:00, $p < .001$; 23:00, $p < .01$), or ending the morning-shift (13:00, $p < .05$). A similar decrease was observed in the middle of the night-shift (02:00) compared to starting the afternoon- ($p < .01$), and night-shift ($p < .05$).

Furthermore, intra-subject correlation scores differed significantly from the null hypothesis for alertness/temperature data ($t(13) = 13.03$, $p < .0001$), alertness/heart rate ($t(12) = 4.47$, $p < .001$) and temperature/heart rate ($t(12) = 7.62$, $p < .0001$). No similar relationship was found between tension and any other measure.

DISCUSSION

As expected, satellite controllers displayed a circadian trend for alertness and oral temperature. In contrast, the trend observed for heart rate, and more especially for tension differed from a typical circadian trend.

In agreement with the literature, reliable circadian trends were observed for alertness and oral temperature (Colquhoun, 1977; Galy et al, 2006; Koscec & Radosevic-Vidacek, 2004; Mélan et al., 2007), despite lack of control over a number of factors known to affect in particular psychological measures in controlled laboratory conditions, including light exposure, noise and motivation (Smith et al., 2002; Wright et al., 2002). Data were recorded on three occasions on each 8-hour shift (1 h following beginning, in the middle and 1 h prior ending a shift), enabling a

2-factor analysis of shift and recording time on shift to be used. Alertness and oral temperature peaked at 15:00, and alertness decreased thereafter to reach its minimum on 02:30, while the oral temperature peak persisted until 21:00, before sharply decreasing until 06:00. Significant interactions indicated that the nocturnal drop was significant both at 02:00 and 06:00 for operators' alertness, and only at 06:00 for their temperature. Thus, alertness decreased earlier in the afternoon and reached its nocturnal trough earlier than oral temperature, thereby extending to a real-job situation the finding of a moderate phase advance of this subjective state variable compared to the objective temperature measure (Edwards et al., 2007; Koscec & Radosevic-Vidacek, 2004; Owens et al., 2000). Though data collected in real-job situations are the result of a complex interaction between the combined actions of the circadian and homeostatic sleep-wake regulation systems and situational factors, and most prominently shift-work itself (Akerstedt, 1991, 2007; Costa et al., 2006; Dinges et al., 1996; Folkard & Tucker, 2003; Glazner, 1991; Knauth, 1996), the present findings fit with the concept of a homeostatic effect upon alertness (Lammers-van der Holst et al., 2006; Van Dongen, 2006). Furthermore, controllers' alertness scores displayed a highly significant correlation with their oral temperature trend that has been closely linked to individuals' metabolism (Colquhoun et al., 1968; Koscec & Radosevic-Vidacek, 2004; Owens et al., 2000; Wright et al., 2002). This result indicates that subjective rating tools may provide a reliable indication about participants' functional state in real-job conditions.

Similar to variations of alertness and oral temperature, heart rate variations resulted from the combined effects of shift and recording-time on shift, with the lowest values observed at the middle and end of the night-shift. In addition, intra-subject comparisons revealed a positive relationship for operators' heart rate and both oral temperature and alertness, indicating that the circadian trend persisted for this measure. This result may be explained by the marked sensitivity of the heart rate rhythm to environmental cues (i.e., zeitgebers), in agreement with other shift-work studies (Khaleque, 1984), and the finding of circadian oscillations of heart rate during sixty hours of sleep deprivation (Miro et al., 2002). On the other hand, the nocturnal heart rate values differed only from those recorded at the start of either shift, whereas for alertness and oral temperature the nocturnal values differed from all six morning- and afternoon-recordings. Thus, operators' heart rate trend differed from a typical circadian trend in that it was increased one hour following each shift-start.

Operators' self-rated tension was also systematically enhanced on the first recording compared to the two remaining recordings of each shift, but contrary to the heart rate recordings, this effect was independent of the shift worked. Several studies have indicated that the circadian variations of negative mood measures may be masked by external factors, including shift-work, time on duty, work-load, sleep fragmentation (Koscec & Radosevic-Vidacek, 2004; Mélan et al., 2007; Thayer, 1978, 1989). Accordingly, in the job-situation examined here, some external factor may have increased operators' subjective tension specifically at shift-start, and in a similar way on all three shifts. The most obvious factor meeting these criteria would be shift hand-over, known to be a critical moment in a shift. If, in the present study, shift hand-over had enhanced operators' perceived tension, this effect should have faded once shift hand-over was terminated, i.e. about 20 minutes after shift-start. This was not observed, however, as increased tension was recorded one hour after shift-start. Alternatively, reduced injury and accident risk within the first half-hour on duty, compared to the second and third half-hour, have been suggested to reflect an increased use of effortful controlled processing (Tucker et al., 2003, 2006). Likewise, taking over the responsibility of a sea watch system has been proposed to account for suppression of sleepiness on the initial duty period, even during the night-watch (Eriksen et al., 2006). Similar "masking effects" may also have been involved following the start of satellite control in the present study.

In line with this hypothesis, supervision of a dynamic process would require an incoming operator to establish a mental model or situation awareness of the system to be controlled, and to plan the sequence of operations to be performed for the remaining time in a shift (Hoc & Amalberti, 1995). Enhanced cognitive work-load during supervisory control has been proposed to account for the significant performance increase observed throughout the first duty-hour of each shift in a chemical plant (Andorre & Queinnec, 1998). Likewise, high levels of activity required when taking over the responsibility of a sea watch system has been suggested to explain initial sleepiness suppression even following reduced sleep duration and on the night-shift (Eriksen et al., 2006). According to the studies, following a critical initial phase, operators would carry out the procedures they had programmed at the beginning of the shift to ensure safety and productivity throughout the rest of the shift, a less demanding duty. A three-process model describing the interaction of task demands, in addition to the well-documented circadian and metabolic factors, successfully simulated the unusual performance profile observed between the start and the main body of the shift (Andorre-Gruet et al., 1998). Given that in the present study operators were also involved in continuous supervisory control activities, aimed at running a dynamic process, it is tempting to propose that high cognitive load induced by difficult shift-change may have accounted for satellite controllers' enhanced tension one hour following the shift-start.

Furthermore, though a similar overall increase was observed for operators' subjective tension and heart rate at shift-start, intra-subject comparison of the two variables across the nine recordings provided no evidence of a significant relationship between participants' heart rate and their self-rated tension. This would then indicate that some external, presumably task-related, factor affected both variables at an individual level, but in a different way. Manipulation of work load, task difficulty, and time pressure have been shown to be associated with an activation of cardio-vascular events, including heart rate, both in controlled laboratory conditions (Backs & Seljos, 1994; Carroll et al., 1986; Fairclough & Kim, 2004; Van Eekelen et al., 2004), and in real-job simulation conditions (Averty et al., 2004; Brookings et al., 1996; Rose et al., 1982). In the latter studies, operators' self-rated workload scores paralleled the heart rate activation, indicating that under high workload operators have to invest more mental effort in order to maintain an adequate level of performance, something associated with heart rate activation. In order to test whether enhanced cognitive load associated with shift-change may have accounted for heart rate activation and increased tension during satellite control, further investigation should include an analysis of task demands in addition to physiological and psychological measures.

Taken together, the present data indicate that despite the fact that shift-workers' capabilities are generally lowest between 03:00 and 04:00 (Folkard & Tucker, 2003), variations in psychological and physiological variables are the product of many different factors including shift-work features, task demands, motivational factors, work/family conflicts, inter-individual differences, and so on (Katie et al. 2006; Kerkhof et al., 2006). Most importantly, these factors may exert a more or less marked influence depending on the measure used. The present findings then support the development of models describing alertness or job-performance by including work-scheduling features, and in particular task demands and duration (Akerstedt et al., 2004; Andorre-Gruet et al., 1998).

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Table 1

Median Heart beats (+/-interquartile range) averaged over the 15 Minutes Prior and the 15 Minutes Following each of the nine Recordings across the 24-h day.

Morning-shift			Afternoon-shift			Night-shift		
08:00	10:30	13:00	15:00	18:00	21:00	22:00	02:30	06:00
81.75	76.35	82.48	84.80	78.33	80.57	83.99	73.64	71.98
5.87	*7.17*	*9.97*	*10.11*	*8.38*	*6.59*	*11.83*	*10.59*	*9.31*

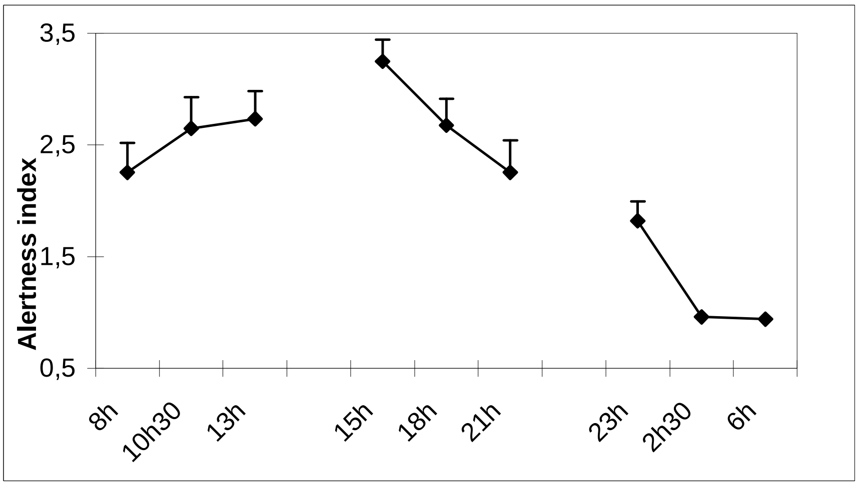
FIGURE CAPTIONS

Figure 1. Upper panel: Mean (+/-S.E.) alertness level on 3 occasions within each of three shifts (1h following shift-start, middle, and 1h before shift-end). Lower panel: Mean (+/-S.E.) sublingual temperature on the same recordings.

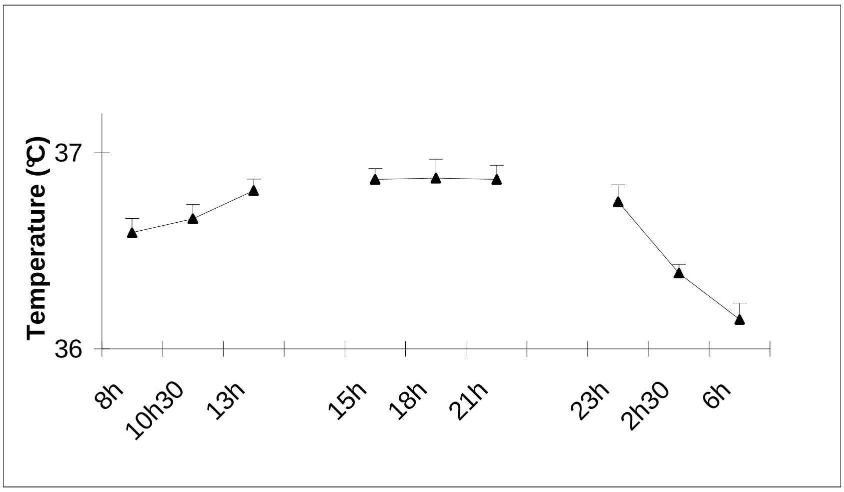
Figure 2. Mean tension (+/-S.E.) provided by self-ratings on 3 occasions within each shift.

Figure 3. Median heart rate (median beats . min^{-1} over 5-min periods per subject, averaged across subjects) across the morning-, afternoon-, and night-shift.

Figure 1.



3,5
2,5
1,5
0,5
Alertness index
8h
10h30
13h
15h
18h
21h
23h
2h30
6h



37
36
Temperature (°C)
8h
10h30
13h
15h
18h
21h
23h
2h30
6h

Figure 2.

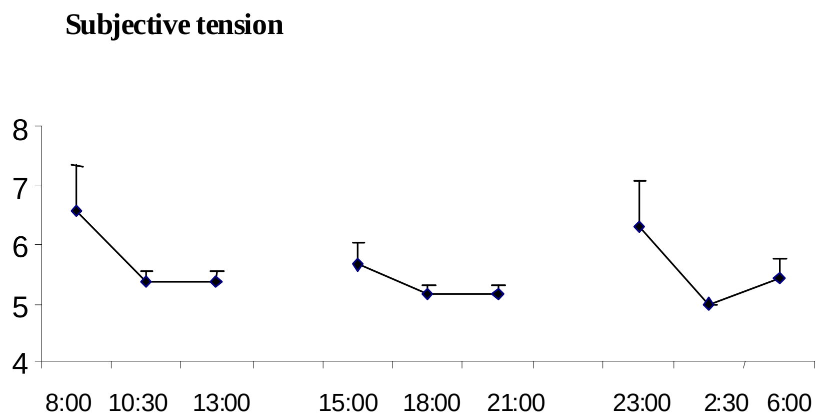
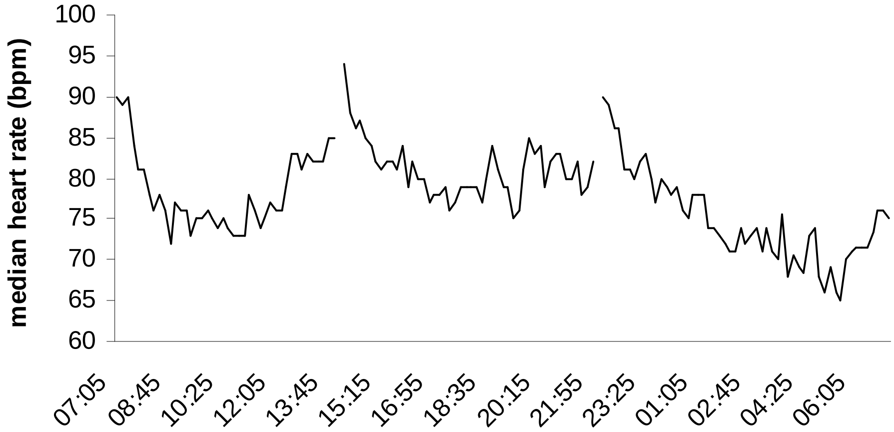

Subjective tension
8
7
6
5
4
8:00
10:30
13:00
15:00
18:00
21:00
23:00
2:30
6:00

Figure 3.


median heart rate (bpm)
100
95
90
85
80
75
70
65
60
07:05
08:45
10:25
12:05
13:45
15:15
16:55
18:35
20:15
21:55
23:25
01:05
02:45
04:25
06:05