State–trait arousal and daytime sleepiness after sleep restriction
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A B S T R A C T

The importance of an arousal system in the regulation of sleepiness has been widely recognised in contexts of insomnia theory and research. Arousal is also incorporated in some general models of sleepiness and is considered one of the principal factors regulating sleepiness in a model by De Valck and Cluydts (2003), in which arousal has both state and trait components. In the present experimental study, we explored the effects of state and trait components of arousal on subjective sleepiness and sleep latency during daytime. On a day after partial sleep deprivation, 28 good sleepers aged 18–26 years took part in two successive experimental conditions, in which the state arousal was manipulated by laboratory tasks. We measured physiological (heart rate, frequency of skin conductance responses) and subjective (Energy, Tension, Anxiety) indices of state arousal, while trait arousal was operationalised as electrodermal lability. After a moderately stressful task, which induced a relatively higher state arousal, the participants reported lower sleepiness and took longer to fall asleep than after a simple psychomotor task. Trait arousal was not associated with daytime sleepiness. The results of this study support the idea that short-term changes of state arousal are important for the regulation of sleepiness in good sleepers, even in a situation which is only moderately stressful.

1. Introduction

Several models of sleepiness (Edgar et al., 1993; Johns, 1998; Cluydts et al., 2002) explain the regulation of sleepiness in terms of two independent opposing processes, usually called sleep drive and wake drive, whose relation determines the level of sleepiness at a particular time. The overall level of sleepiness increases as the sleep drive strengthens and as the level of wake drive weakens, and vice versa.

In the model of sleepiness by De Valck and Cluydts (Cluydts et al., 2002; De Valck and Cluydts, 2003), the wake drive is equally important for the regulation of sleepiness as the sleep drive, and its strength is equated with the level of arousal. Furthermore, this model suggests that both drives have state (short-term) and trait (long-term) components, and implies that sleepiness can also be described in state and trait terms. State sleepiness relates to short-term changes in the level of sleepiness and depends on a specific situation or inner physiological processes, while trait sleepiness reflects stable basal level of sleepiness specific for a person and is independent of situational factors. The model assumes that the level of sleepiness at a particular moment is the result of the trait sleepiness specific for a person and the modifying effects of situational variables, such as duration of wakefulness, time of day or physical activity.

The role of the arousal system in the regulation of sleepiness has been mostly investigated in relation to insomnia. The hyperarousal model of insomnia was confirmed in numerous studies and was recently reviewed from both physiological and cognitive-behavioural perspectives (Bonnet and Arand, 2010; Riemann et al., 2010). There is also evidence that higher levels of autonomic and psychophysiological arousal are associated with decreased daytime sleepiness in normal sleepers (e.g. Kronholm et al., 1995; Pressman and Fry, 1989). Furthermore, several experimental studies (Bonnet and Arand, 1998, 2005a; De Valck et al., 2004; Gross and Borkovec, 1982; Haynes et al., 1981; Wuyts et al., 2012) have shown that transient increases in physiological or cognitive arousal before going to sleep result in a prolonged latency of sleep onset, which indicates reduced sleepiness. A potential limitation of these studies is the use of a single or few indicators of arousal, most commonly heart rate, since arousal is a multidimensional construct and the congruence between different measures of arousal is either small or insignificant (e.g. Clements et al., 1976; Lacey and Lacey, 1970; Matsuda et al., 2009).

The trait aspect of arousal has been conceptualised and explored in relation to sleepiness only poorly. De Valck and Cluydts (2003) refer to the Hyperarousal Scale used in insomnia patients (Pavlova et al., 2001; Regestein et al., 1993) as a possible measure of trait arousal. Following the idea that individuals are characterised by a specific level of arousal which impacts the level of sleepiness (Bonnet and Arand, 2005b; Cluydts et al., 2002), in the present study we introduced electrodermal lability as a potential measure of trait arousal, and explored its associations with subjective and objective sleepiness. Electrodermal lability is usually defined as the frequency of nonspecific skin conductance responses at
rest (Crider, 1993). Individuals who show a high frequency of nonspecific responses are called electrodermal labiles, while those who show few responses are called electrodermal stables (Crider, 1993; Dawson et al., 2000). Electrodermal lability was shown to be relatively stable across time and different situations (e.g. Crider et al., 2004; Crider and Lunn, 1971; Schell et al., 2002), which justify its interpretation as a psychophysiological trait. Furthermore, some studies (e.g. Schell et al., 1988; Kelsey, 1991) have shown that labiles have higher skin conductance levels at rest than stables, and that they also have faster and larger orienting responses, as measured through characteristics of electrodermal responses and changes in heart frequency. In a study by Michael et al. (2012) electrodermal lability was used as an indicator of unspecific tonic arousal and proved to be a good indicator of vulnerability to the effects of total sleep deprivation, with electrodermal stables showing lower subjective sleepiness in comparison to electrodermal labiles.

The aim of the present study was to explore the effects of both state and trait aspects of arousal on daytime sleepiness after sleep restriction. In order to explore the effect of state arousal on sleepiness we chose an experimental design with a paradigm of moderate acute stress, which involved manipulating the level of arousal with short laboratory tasks. State arousal was operationalised with several physiological and subjective indicators to meet the shortfalls of previous studies. In order to investigate the role of trait arousal in the regulation of sleepiness we measured participants’ electrodermal lability and examined its association with the level of subjective and objective sleepiness. The protocol of sleep restriction was chosen because partial sleep deprivation is widely spread in contemporary society, and it contributed to the ecological validity of the study and its practical meaning. A methodological reason additionally supported the introduction of the partial sleep deprivation. Namely, we wanted to measure sleep latency using the standard 20-minute Sleep Latency Test, as measured within the Multiple Sleep Latency Test (MSLT) (Carskadon et al., 1986), the major objective test of sleepiness. The results of MSLT show a ceiling effect after an unrestricted sleep, when the level of daytime sleepiness is relatively low (Horne, 2010; Johns, 2000), and we hypothesised that experimental manipulation of state arousal would reduce sleepiness even below the usual daytime level and increase the ceiling effect. Therefore, the purpose of the sleep restriction was also to improve the sensitivity of the Sleep Latency Test to the effects of varied levels of state arousal.

2. Materials and methods

2.1. Participants

The participants were 28 healthy subjects (14 males) aged 18–26 years (mean ± SD = 21.29 ± 1.78). They were selected from a group of 81 students of psychology who agreed to participate in the study. The participants were informed about the study both orally and in writing and they signed an informed consent. All participants received payment (c. €14 gift voucher) and, where relevant to their course requirements, they were awarded course points for participating in a scientific study. The study was approved by the local ethics committee. The selection was based on a screening questionnaire in accordance with the following criteria: no reported sleep disorders, no serious physical or mental illness, no psychoactive medications, ≤5 caffeinated beverages daily, ≤7 alcoholic drinks weekly, and no night shift work. Additionally, we excluded extreme morning and evening types. The participants reported that on working days they slept between 6 and 9.5 h daily, went to bed between 22:30 h and 01:30 h and woke up between 06:50 h and 21:30 h. A week before coming to the experiment their sleep and behaviour were monitored with sleep–wake diaries and actigraphy to ensure they maintained their usual habits.

2.2. Study design

We used a repeated measures study design with two experimental conditions (see Fig. 1). The two conditions differed in the level of state arousal, which was manipulated by two laboratory tasks: the Simple Reaction Time Task (SRT) and the Combined Speech and Mental Arithmetic Task (CT). Each subject performed both tasks. The order in which tasks were executed was counterbalanced; half of the subjects performed SRT first, and the other half performed CT first. Both tasks were constructed with E-prime (Psychology Software Tools, Inc.) and were computer driven. Their construction was based on a pilot study involving 17 participants.

2.3. Laboratory tasks

The SRT was created in line with the features of the Psychomotor Vigilance Task (Dinges and Powell, 1985). The instruction was to press the space bar on the keyboard as soon as a black dot appeared in the middle of the screen. The stimulus duration was 1 s and inter-stimulus interval was 2–10 s. The duration of the task was 10 min.

The CT was developed according to the Trier Social Stress Task (Kirschbaum et al., 1993) and was performed in front of a webcam. It lasted 10 min and consisted of two parts. In the first part, the participants prepared (3 min) and delivered (3 min) a speech on a given topic. The topic was presented on a computer screen in the form of a question about a socially controversial issue, which was different for each participant (e.g. Do you think violent video games should be forbidden to children?). In the second part, the participants performed a serial subtraction task (4 min). A 4-digit number was presented on the computer screen and the subject’s task was to repeatedly subtract number 17, starting from the presented number, and to pronounce out loud the result of each subtraction. Before CT was performed, the participants were informed that an additional award (c. €7 voucher) would be given for the top 50% scores.

2.4. Procedure

The participants took part in the study individually. They were accommodated in a noise attenuated room with artificial lighting and room temperature between 22 and 25 °C. The instruments for electrophysiological recordings were located in an adjacent room. At least a week before the experiment, the participants received detailed information about the study and participated in a 3-hour session in which all variables were measured in the same way as in the experiment. They were informed about the characteristics of the two laboratory tasks but practised only the SRT. The participants’ electrodermal lability was measured during a 10-minute rest.

The participants stayed in the lab from 22:00 h until early afternoon of the next day (c. 16 h). During the night they slept half of their usual sleep time. The exact sleep schedule and duration were determined separately for each participant based on their sleep diaries from the previous week. The time of going to bed was postponed by half the usual sleep duration on working days. According to diary data the participants went to bed on average at 04:23 h (SD = 41 min), and slept on average 3:46 h (SD = 20 min). Consumption of caffeine and alcoholic beverages was not allowed. Smoking and showering were allowed only until bedtime. In the morning, each participant participated in two experimental conditions (Fig. 1). Each condition lasted for around an hour with a 45 minute break.

2.5. Measures

2.5.1. Daytime sleepiness

Objective sleepiness was measured with the Sleep Latency Test (SLT), which was performed according to the standard MSLT protocol.

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Electrodermal reaction was determined by a consensus between two evaluators. Subjective sleepiness was evaluated with the Karolinska Sleepiness Scale (KSS) (Akerstedt and Gillberg, 1990). This is a 9-point bipolar scale of sleepiness experienced at a particular moment, with every other point described, from 1 — “very sleepy, fighting sleep, difficulty staying awake” to 9 — “very alert”.

**2.5.2. Arousal**

Heart activity and electrodermal activity were measured with PsychLab device and Bioamplifier and SC5 couplers at 400 Hz sampling rate. Heart activity was measured with two disposable Ag/AgCl electrodes attached over the right clavicle and to the lower left side of the thorax. In this study we analysed the minute frequency of the heart beat (HR). Electrodermal activity was measured using exosomatic technique, keeping a constant voltage (0.5 V) between the electrodes. Two reusable Ag/AgCl electrodes (8 mm diameter) were filled with conductive paste (TD-246, Med. Associates) and attached to the medial phalanges of the index and medial fingers of the non-dominant hand. Electrodermal reaction was defined as a change in skin conductance with the minimum amplitude of 0.05 μS (Dawson et al., 2000). For the purpose of this study, we analysed the frequency of skin conductance responses per minute (SCR freq.).

Subjective arousal was measured with the short version of the Activation/Deactivation Adjective Check List (AD-ACL) (Thayer, 1967, 1978, 1989; Croatian version validated by Koscec and Radosevic-Vidacek, 2001). The scale consists of 20 mood descriptors. Using a four-point scale (from 1 — “definitely do not feel” to 4 — “definitely feel”), the participants evaluated how they felt at a particular moment. A total score was expressed as the arithmetic mean of ratings on the items that describe two arousal dimensions: Energy (11 items) and Tension (9 items). Higher scores indicated higher levels of energetic and tense arousal.

The STAI-S subscale of the State Trait Anxiety Inventory (STAI) (Spilberger, 2000) was an additional measure of subjective arousal. It consists of 20 statements that describe feelings of anxiety. The participants evaluated their current state by rating each statement on a four-point intensity scale (from 1 — “not at all” to 4 — “very much”). The total score was calculated as the simple sum of ratings on all items, and it varied from 20 to 80 with higher scores indicating greater anxiety at a particular moment.

Trait arousal was operationalised by measuring electrodermal lability during participants’ first visit to the laboratory after a normal night of sleep, in order to avoid possible effects of sleep deprivation (Miro et al., 2002). It was measured during the 10-minute rest and expressed as the frequency of nonspecific skin conductance responses per minute. It varied from 0 to 7 reactions per minute with mean M = 1.52 (SD = 1.78). In order to evaluate the consistency of individual differences in resting electrodermal lability across situations in this study, correlations were computed between initial values

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**Fig. 1.** (A) Experimental design with two successive conditions. The order of measurements was as follows: (1) physiological arousal (HR, SCR freq.) during the 10-minute rest in a sitting position; (2) subjective arousal (AD-ACL); (3) physiological arousal (HR, SCR freq.) during the 10-minute laboratory task (SRT or CT, counterbalanced between subjects); (4) subjective arousal (AD-ACL, STAI-S); (5) subjective sleepiness (KSS); and (6) objective sleepiness (Sleep Latency Test). HR = heart rate, SCR freq. = frequency of skin conductance responses, AD-ACL = Activation/Deactivation Check List, SRT = Simple Reaction Time Task, CT = Combined Speech and Mental Arithmetic Task, STAI-S = State Anxiety Inventory, KSS = Karolinska Sleepiness Scale. (B) Example plot of the procedure for subject # 031 (22 years, female) whose sleep was restricted from 04:15 to 08:30.
after normal sleep and values for each rest period after sleep restriction on the day of the experiment. Pearson correlations were $r = 0.81$ and $r = 0.76$, indicating a substantial stability of electrodermal lability, as was shown and summarised earlier (Crider et al., 2004), and supporting its use as a trait measure in this study.

2.6. Data analyses

The HR, SCR freq., Energy and Tension scores were analysed with the repeated measures ANOVAs with two within-subject factors: Condition (SRT, CT) and Situation (Rest, Task). For significant interaction effects, simple main effects analyses were used with the Bonferroni adjustment method. The estimations of state anxiety in two conditions were compared with the paired $t$-test. The sleep latency data and the KSS scores were analysed by the means of the linear mixed model analyses. The analyses included a fixed effect for the Condition (SRT, CT), a fixed effect for the Electrodermal lability, and a random effect for the intercept for each subject. The factor Electrodermal lability was modelled as a continuous variable. Since the distributions of sleep latency data significantly deviated from normal, the Spearman correlation coefficient was used to calculate correlations for sleep latency and the Pearson correlation coefficient for the remaining variables.

3. Results

3.1. State arousal manipulation

We first checked if manipulating the level of state arousal with two laboratory tasks was successful. The HR and SCR freq. in two situations from two conditions (Fig. 2) showed significant effects of Condition ($F_{HR}(1,27) = 29.05$, $p < 0.001$; $F_{SCR \text{ freq.}}(1,27) = 96.44$, $p < 0.001$) and Situation ($F_{HR}(1,27) = 66.48$, $p < 0.001$; $F_{SCR \text{ freq.}}(1,27) = 212.53$, $p < 0.001$), as well as their interaction ($F_{HR}(1,27) = 62.71$, $p < 0.001$; $F_{SCR \text{ freq.}}(1,27) = 102.24$, $p < 0.001$). Simple main effects analyses revealed that the HR was significantly higher during the performance of both tasks than during the rest time ($F_{HR}(1,27) = 8.05$, $p = 0.009$; $F_{CT}(1,27) = 68.33$, $p < 0.001$), as was the case with the SCR freq. ($F_{HR}(1,27) = 34.19$, $p < 0.001$; $F_{CT}(1,27) = 211.76$, $p < 0.001$). Furthermore, both HR and SCR freq. were significantly higher during the performance of CT than during SRT ($F_{HR}(1,27) = 48.05$, $p < 0.001$; $F_{SCR \text{ freq.}}(1,27) = 112.38$, $p < 0.001$).

Subjective arousal, measured with Energy and Tension subscales of AD-ACL in two situations after performing two tasks (Fig. 3), also showed significant effects of Condition ($F_{Energy}(1,27) = 16.18$, $p < 0.001$; $F_{Tension}(1,27) = 52.55$, $p < 0.001$) and Situation ($F_{Energy}(1,27) = 17.24$, $p < 0.001$; $F_{Tension}(1,27) = 59.10$, $p < 0.001$), as well as their interaction ($F_{Energy}(1,27) = 62.05$, $p < 0.001$; $F_{Tension}(1,27) = 47.45$, $p < 0.001$). Simple main effects analyses showed that the average estimation on the Energy dimension was significantly higher after performing CT than during the 10-minute rest ($F(1,27) = 50.78$, $p < 0.001$), but the effect was not found for SRT ($p = 0.125$). On the other hand, subjective estimations of Tension were significantly higher after performing either CT or SRT compared to the rest period ($F_{SRT}(1,27) = 8.64$, $p = 0.007$; $F_{CT}(1,27) = 78.82$, $p < 0.001$). Furthermore, comparisons between the tasks showed that estimations for both Energy and Tension were significantly higher after performing CT than after SRT ($F_{Energy}(1,27) = 66.48$, $p < 0.001$; $F_{Tension}(1,27) = 47.53$, $p < 0.001$). The analysis of the measurement of subjective arousal on STAI-S showed that participants felt more anxious after performing CT than after performing SRT ($t(26) = -4.36$, $p < 0.001$).

Therefore, manipulating the level of arousal with laboratory tasks proved to be effective, i.e. the SRT and CT allowed us to create one condition with a rather small increase in state arousal and the second condition with a measurably higher level of state arousal.

3.2. Daytime sleepiness and the level of state and trait arousal

Descriptive statistics for the sleep latency data and the KSS scores in two experimental conditions that differed in the level of state arousal are shown in Table 1.

The linear mixed model analyses for sleep latency showed significant effects of Condition ($F(1,27) = 18.84$, $p < 0.001$). Participants’ sleep latency was longer in the condition with relatively higher state arousal, that is after performing the CT, compared to the condition with relatively lower state arousal, that is after performing the SRT (estimate of the effect size = 4.18, confidence interval (CI) (95%) = 2.10 to 6.15). The effect of Electrodermal lability was not significant ($F(1,26) = 1.81$, $p = 0.190$, estimate of the effect size = 0.82, CI (95%) = -0.44 to 2.09), indicating that electrodermal lability was not associated with sleep latency.

Similar results were found for the KSS scores. There was a significant effect of Condition ($F(1,27) = 5.38$, $p = 0.028$). Participants reported lower sleepiness in the condition with the relatively higher arousal compared to the condition with the relatively lower arousal (estimate of the effect size = -0.71, CI (95%) = -0.08 to -1.35). The effect of Electrodermal lability was not significant ($F(1,26) = 3.27$, $p = 0.082$; estimate of the effect size = -0.31, CI (95%) = -0.66 to 0.04), indicating that electrodermal lability was not associated with subjective sleepiness.

3.3. Correlations between the measures of sleepiness and state arousal

We examined correlations between the measures of sleepiness and a set of state arousal measures. Correlations were computed for each experimental condition separately (Table 2).

Inspection of the table shows that sleep latency and KSS score were moderately correlated with each other in both experimental conditions ($r = -0.52, p < 0.01$ in the SRT condition, and $r = -0.58, p < 0.01$ in the CT condition). In addition, they were moderately correlated with subjective arousal measured by Energy scale of AD-ACL ($r = 0.56, p < 0.001$; $r = 0.61, p < 0.01$ in the SRT condition, and $r = 0.47, p < 0.01$; $r = -0.60, p < 0.01$ in the CT condition).

Fig. 2. Means (±SE) for heart rate and frequency of skin conductance responses (SCR freq.) per minute during rest and task performance in two experimental conditions: SRT = Simple Reaction Time Task and CT = Combined Speech and Mental Arithmetic Task (n = 28); * $p < 0.01$, ** $p < 0.001$. 

Fig. 3. Means (±SE) for Subjective Arousal for Energy and Tension subscales of AD-ACL.
However, the only significant correlation between measures of daytime sleepiness and measures of physiological arousal was found between sleep latency and heart rate in the CT condition (rho = 0.38, p < 0.05).

4. Discussion

In this study the effects of state and trait arousal on daytime sleepiness were explored in good sleepers after their sleep was restricted to 50% of their usual time. Two laboratory tasks, the Combined Speech and Mental Arithmetic Task (CT) and the Simple Reaction Time Task (SRT), were used to induce different levels of state arousal. Measures of both subjective and somatic arousal indicated a relatively higher state arousal in the condition when participants performed the moderately stressful CT in comparison to the psychomotor SRT. The results showed that performance of CT and SRT affected the level of daytime sleepiness to different extents. In the condition with the moderately stressful task, which induced the higher state arousal, the participants required more time to fall asleep afterwards and reported lower sleepiness than in the condition with the simple psychomotor task, which induced the lower state arousal.

Our study shows that active engagement of good sleepers in a moderately stressful cognitive task, which is short and expected, increases somatic and subjective arousal sufficiently to impact sleep latency during daytime. This confirms the findings of previous studies, which have shown that sleep latency increases after short-term changes of cognitive arousal induced by tasks which are minimally (Wuyts et al., 2012) or moderately stressful (Gross and Borkovec, 1982; De Valck et al., 2004). These studies show the effect of arousal moderately after sleep onset (Trinder et al., 2001). It is possible that pre-sleep task may quickly reduce sleepiness arising after sleep restriction to a level similar to daytime sleepiness after unrestricted sleep.

It has been shown that the autonomic activity changes rather rapidly after sleep onset (Trinder et al., 2001). It is possible that pre-sleep changes in the autonomic activity play an important role in the changes in subjective and somatic arousal. However, the results indicate that when good sleepers are partially sleep deprived the effects of elevated arousal on daytime sleepiness are of short duration.

Table 1
Descriptive statistics for sleep latency and subjective sleepiness in two experimental conditions (n = 28).

<table>
<thead>
<tr>
<th>Sleep latency</th>
<th>Subjective sleepiness</th>
</tr>
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<tbody>
<tr>
<td>Median (IQR)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Experimental condition 1 — SRT</td>
<td>4.00 (6.38)</td>
</tr>
<tr>
<td>Experimental condition 2 — CT</td>
<td>9.00 (15.38)</td>
</tr>
</tbody>
</table>

SRT = Simple Reaction Time Task, CT = Combined Speech and Mental Arithmetic Task, KSS = Karolinska Sleepiness Scale, IQR = interquartile range, SD = standard deviation.

Table 2
Intercorrelations for indicators of daytime sleepiness and parameters of physiological and subjective arousal in two experimental conditions (n = 28).

<table>
<thead>
<tr>
<th></th>
<th>KSS</th>
<th>HR</th>
<th>SCR freq</th>
<th>Energy</th>
<th>Tension</th>
<th>STAI-S</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experimental condition 1 — SRT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Sleep latency</td>
<td>-0.52 **</td>
<td>-0.16</td>
<td>0.09</td>
<td>0.56 **</td>
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</tr>
<tr>
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<td>HR</td>
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<tr>
<td>SCR freq</td>
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<td>0.00</td>
<td>-0.34</td>
<td></td>
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</tr>
<tr>
<td>Energy</td>
<td>-0.09</td>
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<td></td>
<td></td>
<td>0.83 **</td>
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<tr>
<td>Tension</td>
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<tr>
<td><strong>Experimental condition 2 — CT</strong></td>
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</tr>
<tr>
<td>Sleep latency</td>
<td>-0.58 **</td>
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<tr>
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<tr>
<td>Tension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.80 **</td>
</tr>
</tbody>
</table>

SRT = Simple Reaction Time Task, CT = Combined Speech and Mental Arithmetic Task, KSS = Karolinska Sleepiness Scale score, HR = heart rate during task performance, SCR freq = frequency of skin conductance responses during task performance, Energy = Energy score on the AD-ACL after task performance, Tension = Tension score on the AD-ACL after task performance, STAI-S = State Anxiety Inventory score.

* Spearman correlation coefficient.
* Pearson correlation coefficient.
* p ≤ 0.05.
** p ≤ 0.01.

Fig. 3. Means (±SE) of Energy and Tension scores on the AD-ACL after rest and task performance in two experimental conditions: SRT = Simple Reaction Time Task and CT = Combined Speech and Mental Arithmetic Task (n = 28). * p < 0.01, ** p < 0.001.
preparation for sleep. Pivik and Busby (1996) found a decrease in heart rate 30 s before sleep stage 1. Furthermore, Morishima et al. (2009) point to the role of the autonomic nervous system in difficulties with falling asleep during daytime. Our study is in line with these findings, as it shows that an increased level of autonomic activity induced by a stressful task interferes with falling asleep during daytime. The participant’s reports of tension and anxiety after a stressful task may have also affected the level of sleepiness, possibly by prolonging stress-related physiological activation (Brosschot et al., 2006).

In order to address the issue of the role of trait arousal in the expression of sleepiness, we used electrodermal lability as a measure of trait arousal. The observed associations between electrodermal lability and measures of sleepiness followed the expected direction (greater lability was associated with lower sleepiness), but were not statistically significant. The present study, therefore, does not indicate that individual differences in electrodermal lability in good sleepers are related either to subjective sleepiness level or to sleep latency in a relatively short daytime period after sleep restriction. Broman and Hetta (1994) found higher electrodermal lability in insomnia patients than in normal sleepers. In addition, they did not find significant association between electrodermal lability and sleep latency of nocturnal sleep in insomnia patients. We can hypothesise that variations of electrodermal lability are restricted to a relatively narrow range in groups of both normal sleepers and insomnia patients; it might then follow that for the combined group variability of electrodermal lability would cease to be a limiting factor for obtaining significant correlations.

The relationship between electrodermal lability and daytime sleepiness has not been systematically explored in previously published work. Two earlier studies (Bohlin, 1973; Siddle and Smith, 1974) compared the level of cortical arousal (EEG activity) in stabiles and labiles while sitting quietly with their eyes closed. In both studies stabiles showed a relatively fast decrease of EEG in the alpha band in comparison to labiles. These results imply that stabiles could generally have a greater sleep-ability compared to labiles, but the finding should be confirmed on a larger sample and with standard measures of sleepiness. Future studies should take into account possible differences in the vulnerability of labiles and stabiles to the effects of sleep deprivation. Specifically, in a recent study by Michael et al. (2012) labiles showed a higher increase in subjective sleepiness during a 48-hour period of total sleep deprivation compared to stabiles; labiles also showed a higher decrease in the frequency of spontaneous skin conductance responses, which was in line with a higher initial frequency of spontaneous responses in that group.

Because of the relatively small sample in our study, we were able to identify only the stronger associations between indicators of sleepiness and state arousal. We found a significant correlation between the heart rate observed during performance of the stressful task and the time taken by participants to fall asleep after the task; participants whose heart rate was higher needed more time to fall asleep than participants whose heart rate was lower. With regard to the indicators of subjective arousal, only the AD-ACL Energy scores were associated with the KSS scores and sleep latency. In Thayer’s model of arousal (Thayer, 1978, 1989), the Energy dimension is closely related to the concept of general arousal and includes states such as feeling sleepy, drowsy, wide-awake and wakeful, which can explain the systematic association of the Energy scores and both measures of sleepiness.

In our study, correlations between sleep latency and the KSS scores were significant and of moderate strength in both conditions. Previous studies on the association between subjective and objective measures of sleepiness have yielded inconsistent results (see Horne, 2010, for a review). Horne has implied that methodological differences could be the source of incongruence between different measures of sleepiness. In our study, the two sleepiness parameters were measured in quick succession and while the participants were lying in bed. These procedures could have reduced some of the methodological differences between SLT and KSS, resulting in their relatively good agreement.

There are some limitations in the present study. First, a relatively small sample size has decreased statistical power in finding significant effects of trait arousal. Another limitation is that we used only electrodermal lability as an indicator of trait arousal, especially when the assumed multidimensional nature of arousal is considered. In the domain of psychological measures there is no standard or widely used questionnaire for trait arousal or wake drive. Potential candidate questionnaires include the Hyperarousal Scale used in two studies of insomnia patients (Pavlova et al., 2001; Regestein et al. 1993) and the Arousal Predisposition Scale used for general populations, whose scores were found to be related to frequency of sleep disruptions (Coren, 1988) and to frequency of dreaming (Hicks et al. 2002). Whereas data on psychometric properties of these two questionnaires are still scarce, properties of electrodermal lability have been widely investigated and extensively reviewed (e.g. Crider et al., 2004). Our data on the cross-situational consistency of electrodermal lability between days with normal sleep and days when sleep is restricted also support the use of electrodermal lability as a trait measure.

In conclusion, this study showed that an increased level of state arousal associated with a stressful task decreased subjective sleepiness and delayed sleep onset during daytime, in spite of a relatively high drive for sleep arising from reduced sleep the previous night. These results indicate that subjective sleepiness and the ability to fall asleep during daytime in good sleepers are sensitive to the influence of rather minor, predictable and short-duration stressors, similar to the stressors to which everyone is regularly exposed. As many real-life stressors are unpredictable in their occurrence and duration, their effects on the ability to fall asleep may be even greater. On a theoretical level, this study confirmed the importance of short-term changes in the level of arousal for the regulation of sleepiness, as suggested in several previous studies and in the model of sleepiness by Cluydts et al. (2002). On the other hand, we found that individual differences in the basal level of arousal, which was operationalised through the measurement of electrodermal lability, were not associated with either the sleep latency or subjective sleepiness. Therefore, we did not find evidence to support the importance of the trait aspect of arousal in the regulation of sleepiness in good sleepers, at least not for the indicator used in this study and the level of statistical significance which could be established for the relatively small sample used.

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