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ORIGINAL ARTICLE

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Disturbed sleep in obstructive sleep apnea expressed in a single index of sleep disturbance (SDI)

Gestörter Schlaf bei obstruktiver Schlafapnoe ausgedrückt in einem Schlafstörungsindex (SDi)

Zusammenfassung Der Schlafstörungsindex (Sleep Disturbance Index – SDI) ist ein neuer, auf Schlafvariablen aus polysomnographischen Untersuchungen basierender Index, der Schlafqualität in einem einzelnen Wert beschreibt.

Er wurde im Rahmen der Lärmwirkungsforschung in Untersuchungen mit eher jungen Probanden entwickelt und getestet. In dieser Untersuchung wird der SDI erstmals in einem klinischen Setting angewendet. 79 Patienten, die mit Verdacht auf Schlafapnoe überwiesen wurden, erhielten eine diagnostische Polysomnographie. Für jede dieser Messungen wurde der SDI berechnet.

Die SDI-Werte dieser klinischen Stichprobe waren höher als die normaler junger Probanden. Die SDI-Werte waren normalverteilt und korrespondierten eng (r = 0,47) mit dem Apnoe-Hypopnoe-Index als Maß der Krankheitsausprägung. Patienten mit ausgeprägteren Atmungsstörungen haben einen höheren SDI, was auf stärker gestörten Schlaf hinweist. Ein explorativer Vergleich der SDI-Werte aus dieser Untersuchung mit SDI-Werten aus Lärmexpositionsstudien zeigt höhere SDI-Werte für die Patientenstichprobe. Der SDI erscheint als vielversprechender Ansatz, Schlaf mit einem einzelnen Wert zu beschreiben und Vergleiche der Effekte von z.B. Umwelteinflüssen und Krankheiten auf den Schlaf zu vereinfachen.

Schlüsselwörter Schlafstörung – Schlafqualität – Schlafapnoe

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Summary The Sleep Disturbance Index (SDI) is a novel index based on polysomnography describing sleep quality in a single score. It was developed and tested with young subjects in the context of research on the effects of noise on sleep. In this study, it is applied in a clinical setting for the first time. A total of 79 patients with suspected sleep apnea received diagnostic polysomnography and the SDI was calculated for these patients.

SDI scores in this clinical sample were higher than those of normal young sleepers. They were normally distributed and showed a rather close relationship (r = 0.47) to the Apnea-Hypopnea Indices as measures of disease severity. Patients with more breathing disorders tend to have a higher SDI indicating more impaired sleep. An explorative comparison of SDI scores of this clinical group with SDI scores obtained in noise exposition studies showed higher SDI scores for the patient group. The SDI seems a promising approach to describe sleep in a single score and facilitate comparisons of the effects of, e.g. environmental and medical factors affecting sleep.

Key words sleep disturbance – sleep quality – sleep apnea

Introduction

Perceived good sleep has a large impact on quality of life. Investigations of quality of life in patients suffering from insomnia, for example, revealed significantly lower scores compared to good sleepers [12, 17]. While the subjective evaluation of sleep quality is certainly not a one-dimensional concept but includes factors like recuperation, performance on the following day, kind and frequency of sleep disruptions during the night, comfort of the bed and multiple other things [5, 16], objective evaluation is also far from being one dimensional [10, 11, 13]. While this might be perceived as appropriate regarding the multiple functions sleep has, it makes it somewhat difficult to describe sleep quality derived from polysomnographic recordings. Based on clinical experience, good sleep is typically associated with the following:

- A relative short sleep latency between 5 and 30 minutes.
- A sufficient, but not excessive amount of slow wave sleep that decreases over the course of the night.
- A sufficient, but not excessive amount of REM sleep that increases over the course of the night.
- A clearly structured sleep pattern containing 4–6 sleep cycles.
- A sufficient, but not excessive duration of sleep.
- Relatively few (up to 6) longer (1–3 minutes) wake periods.
- Relatively few (up to 40) shorter (0.25–1 minutes) wake periods.

While this list certainly does not cover all aspects of good sleep, it is clear that the many aspects of sleep make it difficult to give a simple, clear indication of good sleep and thus lead to problems in comparing the effects of factors that have an impact on sleep. Does an uncomfortable bed turn a good sleeper into an insomniac? Do problems at work impair sleep in a way that is comparable to the sleep disruptions experienced by patients suffering from periodic limb movement during sleep? How do sleep disruptions caused by sleep apnea compare to the disruptive effect that noise can have on sleep?

Without neglecting the multidimensional nature of sleep, it would be helpful to have a single indicator for sleep quality that ideally ought to correspond with objective factors impairing sleep (e.g. number of periodic limb movements, amount of breathing disorders, noise level in the sleep environment), the subjective quality of sleep (e.g. recuperation, sleep continuity), and the effects of sleep (e.g. vigilance, sleepiness and performance during daytime). One attempt to overcome the challenge of taking multiple influencing factors on sleep quality into account has been published by Bruni et al., who created a sleep disturbance scale for children [2] that tries to combine different aspects of the subjective evaluation of sleep into one score. Griefahn et al. [7] have recently developed a sleep disturbance index (SDI) that is based on results of polysomnographic sleep studies and investigated its changes in healthy subjects exposed to overnight noise. A short description is provided in Griefahn et al. (2008, this issue) [9]. Factors contributing to the SDI are wake after sleep onset, time spent in stage nREM1, time spent in stage nREM3/4, time spent in stage REM, latency from lights out to the first of at least four epochs rated as sleep, latency from sleep onset as defined before to the first epoch rated as nREM3/4, and the number of periods rated as wake with a duration of more than three minutes. More time spent in sleep stages nREM3/4 and REM reduces the SDI, while for the other five contributing factors higher numeric values lead to a higher SDI indicating more disturbed sleep.

As the SDI was until now exclusively used in studies with different degrees of nocturnal exposure to noise, we decided to test its usability in patients with suspected sleep apnea. This will also serve to put impaired sleep quality due to noise exposure into a perspective derived from a clinically relevant sleep disorder.

Sleep apnea is a disorder characterized by multiple cessations of ventilation during sleep [15]. These apneas typically occur due to lowered muscle tension during sleep, especially in the pharyngeal area. The negative pressure required for inspiration can, thus, lead to a closure of the pharynx which results in an obstructive apnea. The patient tries to breath (thoracical and abdominal breathing efforts are present), but there is no airflow to the lungs. By definition, apneas have to last at least for 10 seconds. A typical duration is 20–40 seconds, but the longest apnea recorded in our outpatient department had a duration of three minutes. Typically, apneas are terminated by an arousal probably triggered by the accompanying desaturations. This arousal leads to an increase in muscular tension in the pharynx and thus reopens the airway. On the other hand, the activation causes a transition from deeper to lighter sleep or prevents the patient from achieving deeper sleep. The typical result is a lack of slow wave and REM sleep, an increase in light sleep (nREM 2 and nREM1) and frequent transitions between sleep stages often including transitions to wakefulness which are typically not remembered by the patient the next day. For many patients, the main result of this seriously impaired sleep quality is daytime sleepiness, which in turn leads to a 3–7 fold increased risk for crashes [4, 6].

The main purpose of this study is to determine the SDI in patients referred to our sleep disorders center for suspected sleep apnea. We will investigate the distribution of the SDI in a clinical sample and will check specifically whether the SDI follows a normal distribution in this sample. As not all patients will actually suffer from a clinically relevant sleep apnea, we will be able to

compare SDI magnitudes for different disease severities in untreated sleep apnea.

Finally, the degree of sleep impairment of our patient sample will be compared to that obtained in laboratory studies during which young subjects (age 19–28 years) were exposed to different traffic noise levels and qualities [8]. As this will be a cross-study comparison using different populations with different ages, it will be performed in an explorative manner without statistical comparisons.

Methods

All recordings of patients that were referred to our sleep lab for a diagnostic polysomnography due to suspected sleep apnea were eligible for the study. We expected the average SDI of our sample to be at least 2 with a standard deviation of 2, as we know from clinical experience that the sleep of patients with suspected sleep apnea will include patients with very disturbed sleep but also relatively good sleepers. This means a more disturbed sleep with a higher degree of dispersion is to be expected. For healthy subjects, the average SDI is 0 with a standard deviation of 1. In order to describe the SDI of our sample with adequate accuracy, we deemed a 95 % confidence interval of 0.5 to be sufficiently narrow. This means that if we find a mean SDI of 2 with a standard deviation of 2, we need to analyze recordings of at least 60 patients with suspected sleep apnea in order to state that the "true" SDI of the population with the same selection criteria as our clinical sample lies between 1.5 and 2.5 with a probability of 0.95. This would mean that the SDI of the patient group is clearly different from the sample of healthy subjects that the SDI was developed with. In order to obtain at least 60 recordings of sufficient technical quality, recordings from patients diagnosed over a period of five months were included.

Polysomnography was performed according to standard criteria by means of an Embla N 7000 system with the Somnologica Studio software version 3.3.3 (Embla Systems GmbH, Wessling, Germany). Patients were allowed to select their Time in Bed (TIB) according to their wishes or typical schedule within certain boundaries defined by procedural necessities of the clinical sleep lab. This means that Lights Out (beginning of TIB) can not take place before 20:30, Lights On (end of TIB) can not take place later than 7:30. All recordings were evaluated manually by a trained technician (certified by the Deutsche Gesellschaft für Schlafforschung und Schlafmedizin (DGSM)). PSG data including the result of the manual evaluation were exported in Excel format. The parameters required to calculate the SDI were determined by means of Excel routines developed and tested by the authors of this paper.

Statistics

Average values and standard deviations were computed for normally distributed variables to describe the study sample. For variables not distributed normally, the median and the first and third quartile of the distribution are used as measures of central tendency and measures of dispersion. For the SDI, the 95 % Confidence Interval of the mean was calculated. Variables were checked for normal distribution by means of the Kolmogorov-Smirnov One-Sample test. Pearson correlation coefficients were calculated to illustrate the correspondence between the Apnea-Hypopnea Index as a measure of severity of sleep apnea and different sleep variables, the SDI and the ESS score. Partial correlation analysis was used to check the impact of age on the correspondence between the Apnea-Hypopnea Index and different sleep variables, the SDI, and ESS scores. Different magnitudes of the SDI for apnea severity groups were statistically analyzed by means of ANOVA.

All calculations were performed with SPSS vers. 12.01 (SPSS Inc., Chicago, IL, USA).

Results

A total of 86 patients were eligible for participation in the study over the 5 month study period. Seven patients were excluded due to the presence of additional disorders that are known to have a potential effect on sleep quality (4 hyperthyreosis, 1 alcoholism, 1 restless legs syndrome, 1 chronic pain due to polyarthritis). Out of the remaining 79 patients, 17 were females. The mean age was 55.1 ± 11.8 years, the mean bodymassindex was 31.2 ± 5.9 kg/m^2.

As a part of the routine procedure, a diagnostic polysomnographic study was performed. As expected, apnea severity was moderate with 25.4 ± 19.7 apneas per hour. Table 1 displays the Epworth-Sleepiness Scale (ESS) score and sleep characteristics for the sample studied.

The mean SDI for the sample was 2.79 with a stan-

Table 1 Means, standard deviations (SD), minimum (Min) and maximal (Max) values of ESS scores and sleep characteristics for the study sample. For nREM1 and sleep latency, 1st and 3rd quartiles are given instead of standard deviations

	Mean	SD	Min	Max
ESS	9.9	5.2	1.0	22
nREM1 (%)	8.9	5.1–17.1	1.6	79
nREM2 (%)	50.8	13.9	5.9	85.5
nREM3/4 (%)	17.3	10.7	0.0	43.3
REM (%)	18.9	7.7	6.3	42.6
Sleep Efficiency (%)	72.9	13.2	41.3	95.4
Sleep Latency (min)	24.2	11.7–39.9	0.0	322.9
TIB (min)	494.2	61.3	320.0	656.4

dard deviation of ± 1.8. The lowest SDI indicating better than average sleep was –1.24, the highest SDI indicating severely impaired sleep quality was 7.08. The 95 % confidence interval for the SDI of the study sample is ± 0.39. This means that if patients with similar selection criteria as our study sample are investigated, a mean SDI below 2.4 and above 3.18 can be expected with a probability of 0.05. Despite the large difference of the SDI scores of this sample compared to the population it was developed from (mean 0, SD 1), the SDI scores distribution did not differ significantly from a normal distribution (Kolmogorov-Smirnov One-Sample test p = 0.93; Fig. 1).

Apnea severity, SDI scores and sleep variables for the study sample

Apnea severity was expressed as the Apnea-Hypopnea Index (AHI), the number of apneas per hour sleep. A positive, statistically significant correlation between the AHI and the SDI was observed (r = 0.47, p < 0.001; Fig. 2) which indicates that more severe sleep apnea parallels worse sleep quality (higher SDI scores).

The magnitude of the correlations of other sleep variables with the AHI ranged from 0.01 (sleep latency) to 0.46 (percentage REM sleep). As sleep quality is known to decline with age, age was taken into account as a potentially confounding factor and a partial correlation analysis with age as a covariate was performed. There were no substantial changes in the correlation coefficients obtained (Table 2) which indicates that for our sample, age seems to have a relatively similar effect on breathing disorders and sleep quality.

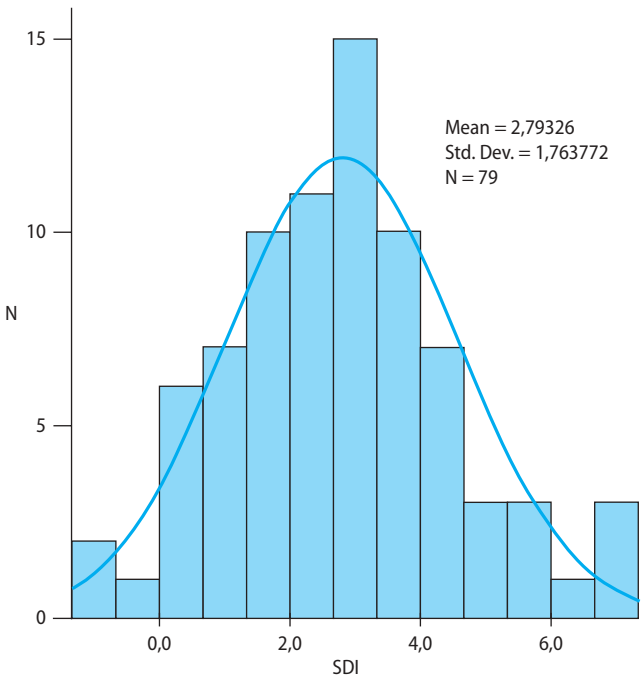

Fig. 1 Frequency distribution of the Sleep Disturbance Index with a normal distribution superimposed

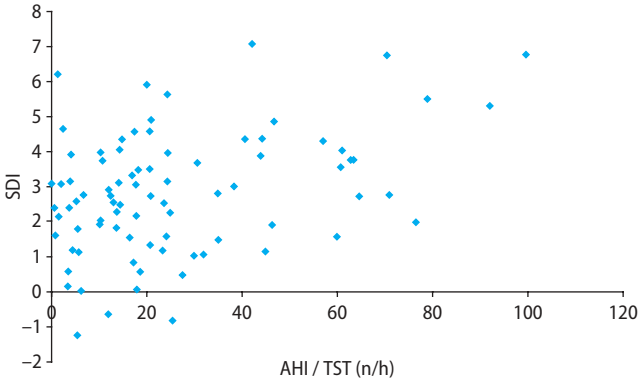

Fig. 2 Scatterplot of SDI scores and Apnea-Hypopnea Indices for all patients

SDI scores and other sleep variables for different apnea severity groups

The study sample was split into three subgroups according to severity of apnea. The grouping was made according to criteria for obstructive sleep apnea outlined in the International Classification of Sleep Disorders [1].

Group 1 contains patients with an AHI between 0 and 4.9. This amount of apnea is typically not considered to be clinically relevant. All patients with an AHI between 5 and 14.9 were placed into the intermediate group 2. Sleep apnea of this magnitude is considered to be clinically relevant only if additional symptoms like, e. g. daytime sleepiness are present. Group 3 consists of patients with an AHI of 15 or more. For patients belonging to this group, clinical relevance of the sleep disorder is assumed independently of accompanying symptoms [1].

Table 3 displays anthropometric data for these three groups.

Table 2 Correlations with the Apnea-Hypopnea Index (r(AHI) and significance level (p), columns 1 & 2); age corrected correlations with the Apnea-Hypopnea Index (r(AHI. age) and significance level (p), columns 3 & 4)

	r (AHI)	p	r(AHI.Age)	p
SDI	0.47	< 0.001	0.47	< 0.001
ESS	0.18	0.15	0.18	0.16
nREM1 (%)	0.19	0.10	0.18	0.16
nREM2 (%)	0.36	0.001	0.33	0.007
nREM3/4 (%)	–0.43	< 0.001	–0.41	0.001
REM (%)	–0.46	< 0.001	–0.47	< 0.001
Sleep Efficiency (%)	–0.19	0.10	–0.17	0.18
Sleep Latency (min)	–0.01	0.93	–0.21	0.87
TIB (min)	0.15	0.19	0.14	0.27

Table 3 Number of patients (N), sex (m = male, f = female), means, standard deviations (SD), minimum (Min) and maximal (Max) values of age, Body Mass Index (BMI) and Apnea-Hypopnea Index (AHI) for apnea severity groups

	Group 1				Group 2				Group 3			
N	7	4 m	3 f		19	13 m	6 f		50	43 m	7 f	
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Age	45.0	13.1	26	59	55.1	10.9	38	79	56.2	11.8	27	85
BMI	29.1	4.4	24.9	37.7	30.2	6.0	22.7	43.0	31.6	5.8	18.7	50.3
AHI	2.4	1.7	0.0	4.4	10.3	3.4	5.2	14.4	38.6	21.9	16.4	99.6

As expected, an increase of the SDI over the three apnea severity groups is observed ($p < 0.05$, ANOVA, Fig. 3). For group 1, the mean SDI was 1.7 ± 1.1, and patients in group 2 had a mean SDI of 2.1 ± 1.4. The highest mean SDI was observed in group 3 (3.1 ± 1.8).

Table 4 gives an overview of ESS scores and different sleep variables for the three apnea severity groups.

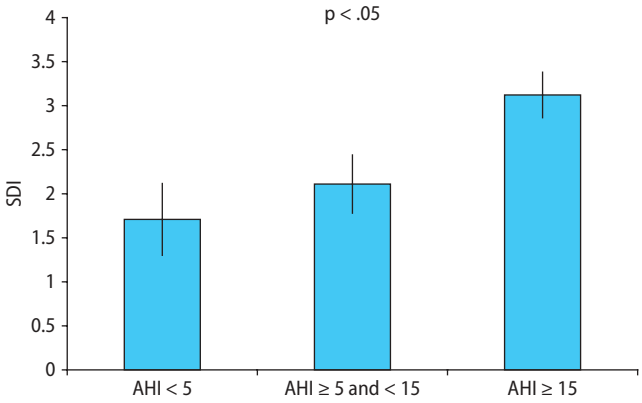

Fig. 3 SDI scores for the three apnea severity groups; error bars indicate the standard error

Exploratory comparison of SDI scores for apnea patients and subjects exposed to different noise levels and noise qualities

The patient sample turned out to be much older (26–85 years) than the sample from the traffic noise studies (19–28 years). Nevertheless, Fig. 4a and b provide a comparison of SDI scores for different noise qualities and degrees of sleep apnea (Fig. 4a) and for different magnitudes of traffic noise and degrees of sleep apnea (Fig. 4b).

It looks like the patient sample has more impaired sleep than the sample exposed to traffic noise. As both samples differ in age and sleep quality is known to be negatively affected by increasing age [14] – for the patient sample, the correlation of age and SDI score is 0.23, $p < 0.05$ – the relative contribution of age and sleep apnea to the differences observed remains unclear. The results do show that despite the effects of noise and medical disorder, each group contains some relatively good sleepers who manage to have an SDI close to (AHI < 5) or below zero. We would speculate that if the AHI < 5 group had more than just 7 patients, it would also contain sleepers that reach an SDI below zero which indicates better than average sleep.

Discussion

The results of this study show that the SDI, a novel index describing sleep disturbance based on polysomno-

Table 4 Means, standard deviations (SD), minimum (Min) and maximal (Max) values of ESS scores and sleep characteristics for the apnea severity groups. For nREM1 and sleep latency, 1st and 3rd quartiles are given instead of standard deviations

	Group 1				Group 2				Group 3			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
ESS	11.5	3.9	5	17	9.0	5.2	2	22	9.8	5.2	1	20
nREM1 (%)	5.1	2.8–11.2	2.5	12.7	10.3	6.0–16.7	2.7	79.0	9.0	5.1–21.3	1.6	52.8
nREM2 (%)	47.1	7.2	37.3	56.1	47.4	12.3	22.4	68.6	52.6	15.0	5.9	85.5
nREM3/4 (%)	18.3	4.2	11.5	23.5	19.6	10.2	3.7	42.4	16.3	11.5	0.0	43.3
REM (%)	27.7	10.4	14.8	42.6	21.6	5.5	13.3	34.1	16.6	6.9	6.3	35.3
Sleep Efficiency (%)	77.5	11.5	62.9	93.9	78.8	10.2	61.6	95.4	70.1	13.8	41.3	94.8
Sleep Latency (min)	20.9	12.7–74.2	0.0	249.1	16.8	8.6–30.6	3.0	162.1	24.8	13.9–43.7	0.6	322.9
TIB (min)	496.7	74.8	381	601	489.3	49.2	426.9	578.1	495.0	65.0	320.0	656.4

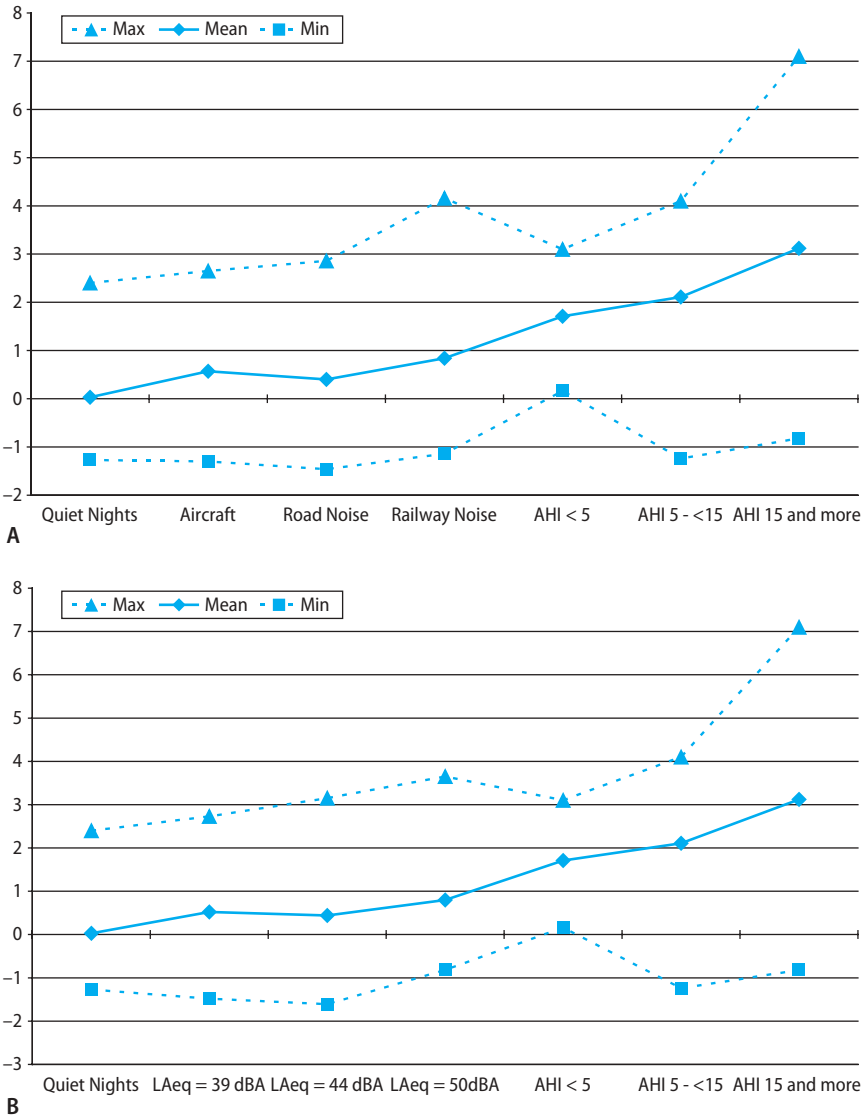

Fig. 4 **A** Maximal, mean and minimal SDI scores for different traffic noise qualities and apnea severity groups. **B** Maximal, mean and minimal SDI scores for different traffic noise intensities and apnea severity groups

graphic variables, is suitable for describing sleep of patients suffering from sleep apnea. This is true despite the fact that the SDI was developed based on recordings performed in an experimental setting with young, healthy subjects exposed to noise of varying equivalent levels within a fixed TIB of 8 hours, whereas the recordings used in this study stem from clinical routine which is reflected, e.g. in the high variability of the TIB duration (5 h 20 min to nearly 11 h). Furthermore, patients of this clinical sample are much older than the samples with which the SDI was developed. For patients with suspected sleep apnea, increasing disorder severity is associated with a higher SDI. Like other variables describing sleep or sleep disturbance in patients with sleep apnea, SDI scores show a high interindividual variability in patients with similar disease severity. An AHI in the range of 20 phases per hour of sleep can result in an SDI of 0 indicating unimpaired sleep as well as in an SDI of 6 indicating massively impaired sleep (Fig. 2). In our judgement, this is no indication for a shortcoming of the SDI but shows that there is high interindividual variability in the pathophysiological connection between disordered breathing and sleep quality.

The fact that the SDI scores are normally distributed in this patient group is noteworthy as this facilitates statistical comparisons and analysis of interdependence of the SDI with other variables.

In our sample, the amount of slow wave sleep and REM sleep was equally well associated to apnea severity as the SDI. While one could argue that this negates the necessity of a new index, we are not certain whether this is the case. It does seem to indicate that the sleep disturbance of our sample has a lot to do with less REM and slow wave sleep with increasing apnea activity. For other

samples with different factors impairing sleep (e.g. insomnia, periodic limb movements during sleep, posttraumatic stress disorder, depression), a high SDI could well be caused by other influences, e.g. high amount of sleep stage nREM1 and frequent periods of wakefulness without a high impact on slow wave sleep and REM. If this speculation turns out to be true, the SDI could indeed be a good tool for cross-sample comparisons of sleep.

It seems certainly promising to follow-up on the concept of the SDI and to test its usability to demonstrate the effects of different sleep disorders on sleep quality and to check its sensitivity to treatment effects. Furthermore, it will be interesting to compare the SDI and other sleep variables for their associations not to factors affecting sleep but to variables affected by sleep like results of vigilance and sleepiness testing, subjective ratings of sleep quality, and performance in different areas like declarative and procedural memory.

While the SDI is intended to describe sleep disturbance, it does seem somewhat counter-intuitive to us. A negative SDI is associated with better than average, in other words good sleep, a positive SDI is associated with poor sleep. This is typically discouraged in questionnaire development and item construction [3]. If we think about sleep, we tend to associate negative numbers with poor sleep and positive numbers with good sleep. Even after working with the SDI for a few months now, we still do not tend to think in the (negative) concept of sleep disturbance but in the more general "sleep" concept. If many others have a similar tendency like those of us working in clinical sleep medicine, one might consider substituting the SDI or its next iteration with the Sleep Quality Index (SQI) which could simply be 0-SDI. But this is at present certainly premature as the SDI was as yet exclusively validated for impaired but not for improved sleep.

Despite this minor criticism which might say more about inflexibility of sleep clinicians than about an actual shortcoming of the SDI, we were surprised how well the SDI could be applied in clinical sleep medicine. Despite the very different sample characteristics, it is normally distributed and has a rather close relationship to clinical indicators of disease severity like the AHI. It seems to be a very promising approach to integrate sleep disturbance into one index, the SDI.

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Conflict of Interest None.

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