Long-term Monitoring of Movements in Bed and Their Relation to Subjective Sleep Quality

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The development of sensitive movement detectors has stimulated interest in nocturnal motility. As no first night effect (FNE) has been found in motor activity, single-night recordings have sometimes been suggested sufficient as an objective measure of sleep quality. The aim of the present study was to investigate the stability of movement based activities over a two week period. The body motility, respiratory movements, and ballistocardiogram of 16 healthy subjects were registered using the static charge sensitive bed (SCSB) across 14 consecutive nights at their homes. The automatically analyzed SCSB data were also compared to the nightly variations in subjective sleep quality. No major systematic tendencies were found in motility during the registering period, but a subjective FNE was obvious. There was great inter-subject variation in motor activity, but noteworthy intra-subject differences were also found. The correlations between subjective and objective measures across the 14 nights quite systematically indicated better subjective sleep quality as a function of low motility. A more systematic relation was revealed when the subjective evaluations of the nights representing the extremes of motor activity were compared with each other, increased activity indicating subjectively distorted sleep. Both the great inter-individual differences in motility and the unsystematic but remarkable variation within subjects suggest that, at least as regards small samples of subjects, very much cannot be inferred from single-night movement recordings. Consequently, if motility is intended to be used as an indicator of sleep quality more than one recording night is often advisable in order know the individual motor baseline. **(Sleep and Hypnosis 2003;5(3):145-153)**

Key words: *body movements, SCSB activity analysis, inter- and intra-individual variation, subjective sleep quality*

INTRODUCTION

Standard sleep polygraphy with EEG, EOG, and EMG recording (1) or the modern polysomnogram including even more physiological parameters has been infrequently applied in long-term follow up studies with an extended number of subjects. These methods usually presuppose a laboratory setting which can be considered as too laborious and expensive for some applications. Additionally, the sleep laboratory can have known effects (first-night effect, FNE) on sleep architecture (2), in some cases even paradoxial ones (3). There is a need for objective methods which are uncomplicated and cost-effective, and which can be applied in natural sleeping

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environments.

Increased motility is one of the most obvious overt signs of distorted sleep, probably reflecting heightened psychophysiological arousal (4). Various kinds of movements occur during normal sleep, although there are differences in the number and duration of them between sleep stages (5-8) and between individuals and nights (9-11). Some amount of gross body movements are presumably needed to avoid discomfort and to maintain sleep whereas short lasting twiches are normal phenomena during REM sleep. Previous studies have not revealed any FNE in motor activity (10-12) and therefore single-night recordings have been suggested as sufficient as sleep quality measures.

The appearance of new sensitive movement detectors has increased the interest in nocturnal motility. The static charge sensitive bed (SCSB) was developed to register different kinds of movements from the whole area of the bed (13). In addition to ordinary body movements like postural shifts or twiches of the limbs, respiratory movements and those caused by the recoil power of the pumping action of the heart (ballistocardiography, BCG) can also be registered by using specific filterings and amplifications of the raw SCSB signal (14). The method has been used as a movement detector both in human (4,10,15-19) and animal studies (20-21). Several studies using different combinations of the three SCSB signals have suggested that SCSB recordings reflect the general cyclic variations in EEG sleep (22-29). Automatically analysed SCSB data were a few years ago (27) compared with the standard sleep stages (1). The variability of respiratory and BCG signals and the number of short body movements were used to categorize the recordings into quiet (QS), intermediate (IS), and active (AS) states. SCSB activity during wakefulness, stage 1 and REM sleep were mostly scored as AS. SCSB data during stage 2 and especially during slow wave sleep (stages 3 and 4) predominantly consisted of QS or IS.

The purpose of the study described below was to investigate the variations in SCSB recordings in normal sleepers during 14 consecutive nights. Inter- and intra-individual changes of both body movements of different durations and the activity states (QS, IS, AS) were analyzed. The SCSB data were also compared with the subjective evaluations of sleep quality.

METHODS

Sixteen paid (350 FIM) volunteers (8 females/8 males, mean age 26.2) with no serious sleep difficulties or somatic complaints served as subjects. Body motility was registered during 14 consecutive nights by using the SCSB sensor in the subjects' own beds at their homes. The recording period always started on a Monday evening and ended on a Monday morning two weeks later. The respiratory movements and the BCG were filtered from the raw movement signal and further amplified by a BR-CPA8 preamplifier and the three resulting signals were recorded with a four channel Oxford Medilog 4-24 or a seven channel Teac HR-30 cassette recorder. The subjects were carefully instructed in advance how to use the recording equipment. Their task was to switch on the preamplifier, the external power source, and the tape recorder at 'lights out', to switch them off after final awakening in the morning, and to change the cassettes which were provided with the date and the running number of the night.

Subjective reports of sleep quality were collected every morning using a questionnaire. The items included the times of 'lights out' and final awakening, estimated sleep latency, number of awakenings, estimated time spent awake after initial sleep onset, and the estimated total sleep time (TSTE). The rest of them dealt with the subjective quality (very good - very bad), restfulness (very restful - very restless), and depth of sleep (very deep - very light) on a five point scale. Similar rating scales were used to compare the quality, restfulness, depth, and sleep latency of the previous night with the habitual sleeping pattern. The subjective sleep efficiency percentage was computed as (TSTE/time in bed)*100.

The SCSB signals were reproduced at high speed (16 and 32 * real time for Oxford and Teac playback units respectively) and digitalized by a Data Translations DT 2801 A/D converter. The data were analyzed using the commercially available BR01 software, which has been developed for the automatic off-line analysis of SCSB recordings (Biorec OY, Finland). At the beginning of the BR01 analysis the movement detection level was set as three times the BCG artifact amplitude on the movement channel. Body movements were automatically classified into four categories according to their duration; Class A < 5 sec, 5 sec < B < 10 sec, 10 sec < class C < 15 sec, and class D > 15 sec. These categories have been suggested by Alihanka (6,30) and were also used by others (10,18). BR01 counts the absolute number of movements in each class and their temporal frequency, and it also provides the absolute movement time and its percentage (MT%). Nevertheless, in the present study classes B - D were combined as gross movements (GM) and class A was called small movements (SM). Only MT% and the movement frequencies in relation to time (GM/min and SM/min) were used in the analyses. QS, IS, and AS were defined according to the classified sum score of the number of movements lasting < 10 sec, respiratory amplitude variation, and BCG slow variation provided by BR01 for each 3 min epoch (27). For the analyses, the motility parameters (SM, GM, MT%) and the percentages of QS, IS, and AS were calculated separately for the time in bed (TIB), for the first hour (FH) and for hours 2-6.

Analysis of variance (ANOVA) was used in analyses of the variations between nights (repeated measures) and between subjects. Differences between individual nights were studied by using the Student's t-test and the Wilcoxon matched-pair signed-ranks test. On five occasions out of the 224 nights, SCSB recording failed due to forgetting to switch on the recorder or the SCSB preamplifier before falling asleep or because of technical problems. The analyses of the variations between nights and between subjects as well as the correlations between subjective reports and SCSB measures were based on the data of the successfully recorded nights. Mean values of each subject's successful recordings were substituted for the missing data in the graphic illustrations.

RESULTS

The repeated measures ANOVA did not reveal significant differences in any movement

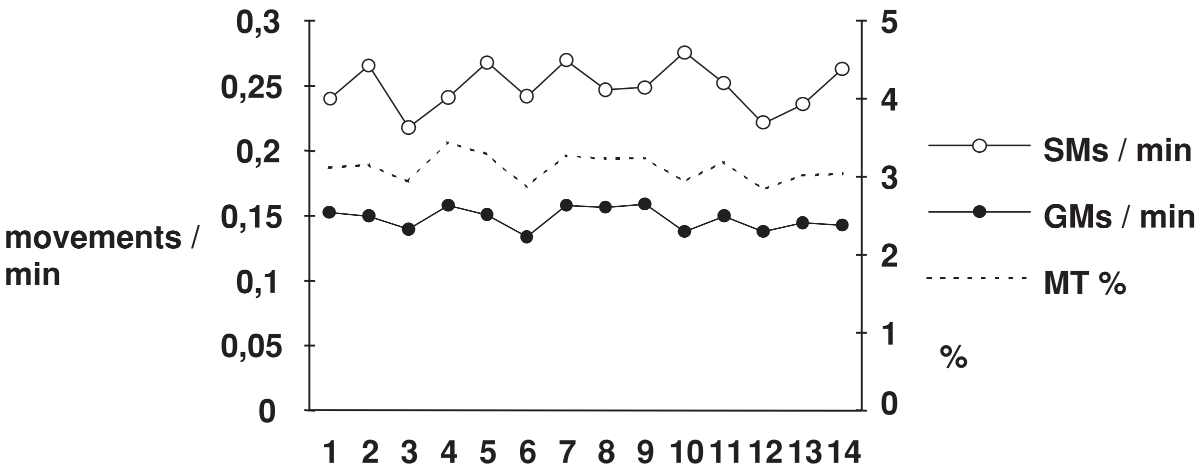

Figure 1. The means of movement parameters (per TIB) across 14 consecutive nights.

parameter between the 14 nights (F(13/190)=non significant each). There were no significant differences in motility between the means of recorded weeks or between the nights before working days (Mon-Fri) and before days off (Sat-Sun). Nor was any systematic FNE found in the movement data between the first night and the three subsequent nights. There were, however, differences in motor activity between certain consecutive nights. The greatest difference was observed in the frequency of gross body movements (GMTIB) between nights 6 and 7 (two-tailed t= -3.07, p=.008, df=15). Significant (p<.05) changes between consecutive nights were found also in other movement parameters, except in small movements (SMTIB, SMFH, SM2-6), but systematically only between nights 6 and 7. The means of some movement parameters during the two week period are presented as an example in Figure 1.

Table 1. ANOVA results on the inter-subject differences in motor parameters

Variable	Grand mean	$SS_{Main\ eff.}$	$SS_{Resid.}$	F(15,203)[a]	Multiple R^2
SMTIB	0.249	2.33	0.73	43.55	0.763
SMFH	0.279	4.95	5.18	12.92	0.488
SM2-6	0.232	2.25	1.06	28.77	0.680
GMTIB	0.148	0.25	0.21	16.60	0.551
GMFH	0.186	1.41	3.05	6.23	0.315
GM2-6	0.135	0.35	0.33	14.53	0.518
MT%TIB	3.114	163.69	88.72	24.97	0.649
MT%FH	3.990	659.96	1159.26	7.70	0.363
MT%2-6	2.834	193.57	140.54	18.64	0.579

$SS_{Main\ eff./Resid.}$ = Sum of squares, Main effects/Residual
SM = short movements/min, GM = gross movements/min,
MT% = percentage of movement time.
TIB = time in bed, FH = the first hour in bed, 2-6 = hours 2-6.
[a] p< .001 for all movement parameters.

The inter-subject variation was significant for every movement parameter (Table 1). According to the ANOVA [F(15/203)] it explained 31-76% of the variance of different parameters, and it was greater than the residual variance for all of them except those during the first hour in bed. The most considerable inter-subject differences were found in the number of small movements during TIB. The inter-individual variation accounted for 64.9%, 76.3%, and 55.1% of the total variation of MT%TIB, SMTIB, and GMTIB respectively.

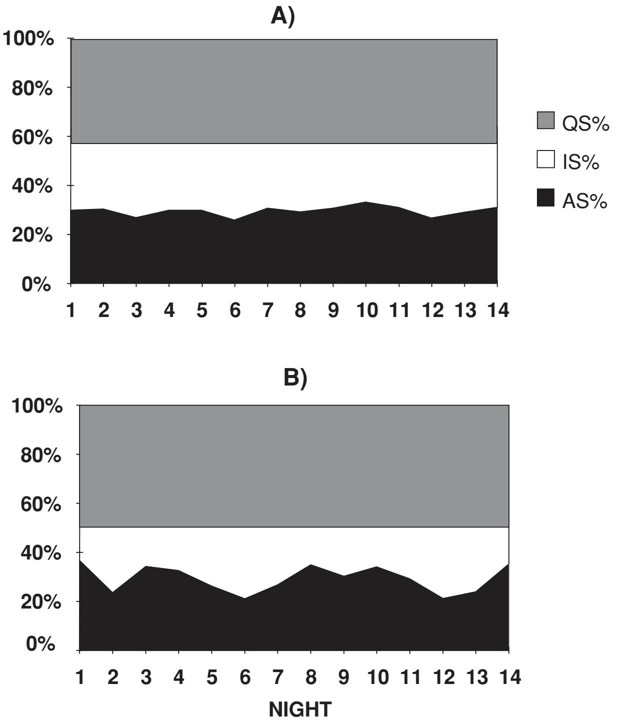

Figure 2. The mean distribution (area) of the SCSB activity states over the 14 nights. A) during TIB and B) = during the first hour in bed.

Table 2. Intra-individual minimum and maximum of nocturnal movement time ($MT\%_{TIB}$) and the amount of active state ($AS\%_{TIB}$).

	$MT\%_{TIB}$		$AS\%_{TIB}$	
subject	min	max	min	max
1	1.48	3.67	14.8	40.4
2	1.74	3.13	22.2	42.8
3	2.65	3.66	2.8	17.8
4	1.37	2.35	24.4	42.7
5	1.51	3.13	4.8	20.3
6	1.89	5.54	2.0	24.5
7	2.32	4.12	21.7	36.8
8	1.62	4.44	23.2	36.8
9	2.82	5.86	41.1	62.0
10	2.90	4.75	23.3	47.9
11	3.52	7.39	34.4	69.1
12	1.49	2.38	20.3	42.1
13	1.54	2.72	13.6	33.3
14	3.08	5.29	17.2	37.1
15	3.18	5.11	28.6	43.9
16	2.38	5.91	19.0	47.2
Mean	2.22	4.34	19.6	40.9
SD	0.73	1.45	10.6	13.4

The ANOVA results concerning the differences in the percentages of QS, IS, and AS, were similar to those found in general motility. The contribution of inter-individual variability was significant [F(15/203)], p<.001) for all activity parameters and varied between 26-80%. The mean percentages of the activity states during the 14 nights are presented in Figure 2 for TIB (A) and for the first hour in bed (B). A significant (p<.05) difference was found in QS%FH between the first and the second night. However, the means of QS%FH during nights 3-5 did not differ from the first night.

Each subject's minimum and maximum values of MT%TIB and AS%TIB across the 14 nights are presented in Table 2 as examples of the differences between the individual extremes in motor based activity. The differences were obvious in all subjects and the means of both parameters showed approximately twofold greater activity during the most active night as compared with the least active one (MT%TIB: 2.2-4.3%, AS%TIB: 19.6-40.9%). Similar ranges were found in the other activity parameters during TIB (e.g. means of SMTIB and GMTIB: 0.16-0.36 and 0.11- 0.21, respectively), but manifold differences appeared between the extremes during the first hour in bed (means of SMFH, GMFH, MT%FH, and AS%FH: 0.08-0.54, 0.06-0.39, 1.8%-8.3%, and 8.1%-53.1%, respectively). The individual minimum or maximum values of different variables did not appear during the same night: e.g. the maximums of both MT%TIB and MT%FH of five subjects, and those of both MT%TIB and AS%TIB of four subjects took place during the same night, but only one subject had the highest values of all three parameters during the same recording.

The mean ratings of subjective sleep quality, restfulness, and depth are presented in Figure 3 together with the estimation of sleep efficiency. A clear subjective FNE was obvious in the questionnaire data. According to the Wilcoxon test the improvement in sleep quality, restfulness, depth, and efficiency as well as the shortening of estimated sleep latency was significant between nights 1 and 2 (Z values -2.47, -2.27, -2.40, -2.04, -2.90, respectively, p<.05 for all except for latency, p=.004). The ratings of the first night also differed from those of the following (3-5) nights. A significant change in the opposite direction was observed between nights 6 and 7 in all of the previous parameters and also in them compared with the habitual sleeping patterns.

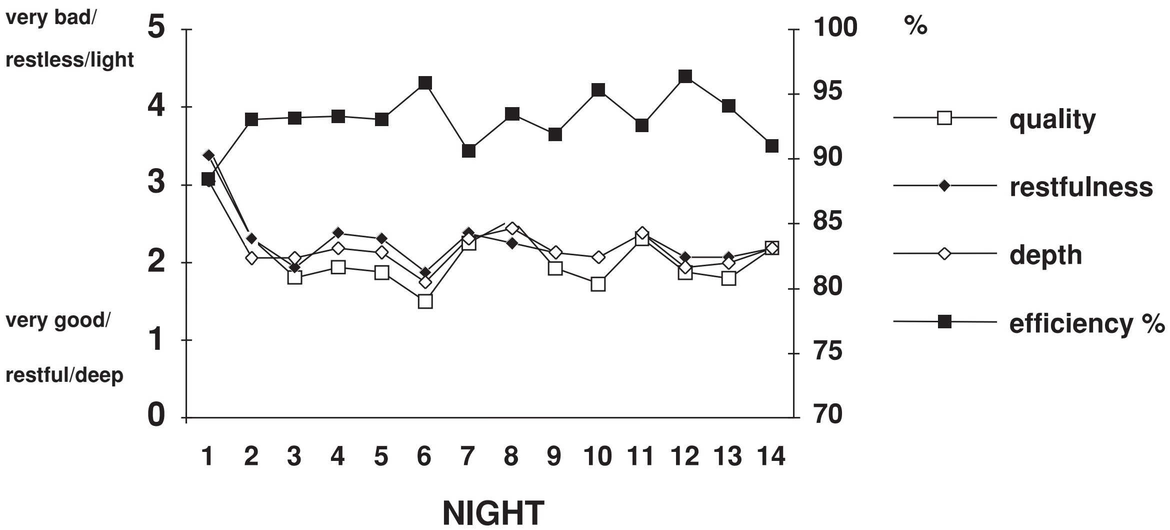

Figure 3. Averaged ratings of selected parameters of subjective sleep quality across 14 nights.

For correlation analyses an index of general sleep quality was calculated as the sum score of seven subjective parameters (sleep quality, restfulness, depth, and these three plus sleep latency compared with the habitual sleeping pattern), a greater score indicating poorer subjective quality of sleep. Correlation coefficients between two subjective and two objective parameters are presented in Table 3 for each subject across the 14 nights. For the majority of subjects MT%TIB and AS%TIB correlated negatively with the sleep efficiency estimation and positively with the poor general sleep quality. The correlations were systematic but only between MT%TIB and subjective sleep efficiency did more than half of the subjects show statistically significant coefficients. Similar relations were found between the rest of the objective-subjective comparisons: for most subjects and for most of the SCSB parameters (except small movements) there were positive correlations with subjective sleep latency and poor sleep quality and negative ones with sleep efficiency. However, statistically significant correlations coefficients were found among less than half of the subjects. The correlations between the estimated number of awakenings and the SCSB parameters were generally low and ambiguous.

Table 3. Within-subject correlations (across 14 nights) of nocturnal movement time ($MT\%_{TIB}$) and the amount of active state ($AS\%_{TIB}$) with estimated sleep efficiency and the general sleep quality (sum score of seven subjective parameters).

	Sleep efficiency estimation		Sleep quality (sum score)	
subject	$MT\%_{TIB}$	$AS\%_{TIB}$	$MT\%_{TIB}$	$AS\%_{TIB}$
1	.05	-.09	.02	.03
2	-.00	-.32	.52	.46
3	-.35	-.51	.51	.60*
4	-.45	.15	.04	-.16
5	-.84***	-.69**	.33	.21
6	-.84***	-.26	.17	-.32
7	-.32	-.22	.27	.28
8	-.66*	-.25	.23	-.20
9	-.59*	-.31	.79**	.48
10	-.67**	-.06	.71**	-.04
11	-.61*	-.34	.84***	.78**
12	-.15	.09	.15	-.21
13	-.70**	-.51	.52	.39
14	.13	-.16	.03	.21
15	-.54*	-.11	.75**	.23
16	-.73**	-.31	-.21	-.24

* p<=.05; ** p<.01; *** p<.001

Fourteen out of the 16 subjects reported poorer sleep during the night with the highest MT%TIB as compared with the night with the lowest MT%TIB. For the whole group the means of general sleep quality (range 7-35) were 16.8 (SD 3.7) and 23.8 (SD 6.2) for the individual minimum and maximum of MT%TIB respectively (t=-5.04, df=15, p<.001). In respect of the MT%TIB the means (and SDs) of the least and the most active nights were 95.0% (4.8) and 86.0% (9.6) for estimated sleep efficiency (t=3.43, p<.01), and 14.1 min (14.7) and 37.3 min (34.9) for subjective sleep latency (t=-2.86, p<.05). Similar kinds of differences in subjective parameters were found between the individual extremes of GMs and the AS%, but not with those of SMs. There were no significant differences in the estimated number of awakenings between the extremes of any motor parameter.

DISCUSSION

The present study aimed at investigating the inter-individual differences and the night-to-night variations in nocturnal motility in bed and in activity states (QS, IS, AS) defined according to body movements, respiratory movements and the ballistocardiogram. The activities were registered over 14 consecutive nights by the SCSB method and the records were compared to the ratings of subjective sleep quality.

No FNE was found in relation to body movements. There was a significant difference between the first and the second night in the amount of QS during the first hour in bed, but this can hardly be regarded as a sign of FNE in the usual sense because the values returned almost to the initial level during the subsequent nights. On the other hand, the FNE was obvious in most of the subjective measures. It could be speculated whether a subjective FNE is a natural response when serving as a subject whose somatic functions are recorded and whose subjective experiences are repeatedly questioned, even though this all takes place in a familiar environment. Nor did any other systematic tendencies appear in the SCSB recordings except the significant increase in motility between nights 6 and 7. This change, perhaps indicating the beginning of a new recording week, was also manifest in the subjective sleep quality.

The differences between individuals accounted for more than 50% of the total variation of each of the motor parameters during the total TIB. In spite of these great inter-individual differences considerable intra-individual changes in the SCSB variables also appeared during the two weeks. The individual maximum values during TIB were on average twice as large as the individual minimums, and even greater differences were found in activity during the first hour in bed. Movement time and the number of gross body movements have traditionally been considered as quite stable sleep parameters (10,31). However, the present results confirm the suggestion of Kronholm et al. (10) that the absence of systematic variations in motility between nights does not indicate that there were no intra-individually significant differences.

The correlations between subjective and objective measures across the 14 nights quite systematically indicated better subjective sleep quality as a function of low motility. Nevertheless, only between the percentages of movement time and estimated sleep efficiency did more than half of the subjects show statistically significant correlation coefficients. A more systematic relation between subjective and objective variables was revealed when the subjective evaluations of the nights representing the extremes of activity were compared with each other. The extremes of movement time, number of gross movements and the amount of AS were related to subjective sleep quality but no relation was found between the extremes of small movements and the subjective measures.

Previous studies concerning the relationship between nocturnal motility and sleep quality have usually concentrated on the group differences between good and poor sleepers (10,32-33) or between specific patient groups and controls (e.g. 16,18). Kronholm et al. (10) found an almost twice higher movement frequency in poor sleepers than in good sleepers, but there were great inter-individual differences in gross body movements in the latter group. They also reported on their good sleepers that, in agreement with Merica and Gaillard (9), the intra-individual variance of small body movements was greater than the variance between individuals. As the poor sleepers exhibited the same in both small and large movements Kronholm et al. (10) concluded that a considerable increase in intra-individual variation of large movements (>5 sec) would be a manifestation of a sleep disturbance. The present results emphasize the significance of the inter-individual differences in both small and large body movements in normal sleepers. In contradiction with Merica and Gaillard (9) and Kronholm et al. (10), the greatest between-subjects effect (76.3%) on the variability of different movement variables was found in small movements. Nevertheless, the conclusions concerning motility and quality of sleep are parallel with those of Kronholm et al. (10). The subjective estimations of sleep quality of the most active nights with respect to gross movements clearly differed from those of the least active ones, and consequently gross movements (as well as some other motility based parameters) are related to sleep quality. On the other hand, even considerable individual differences in small body movements do not seem to be reflected in subjective sleep quality.

The cost and laboriousness of polysomnography makes it difficult to be applied in follow up sleep studies with a lot of subjects. The unobtrusive recording of nocturnal movement activity appears to be a promising possibility. The SCSB recording provides a good general view of overall activity in bed but the method also has its natural limitations. The location or origin of a movement cannot be detected with the SCSB, e.g. twitches of the head, a hand or a leg are similarly displayed. If needed, this kind of phenomena can only be differentiated by using multiple EMG channels, actigraphs, or other sensors at different locations on the body.

Earlier laboratory studies on the relationship between EEG based sleep and SCSB analysis (e.g. 23,25-28) imply that the recording of body movements and the motor manifestation of autonomic nervous activities could provide a simple and inexpensive objective indicator of sleep quality in adults. In the present study the long-term changes in various SCSB parameters were investigated amongst "good" sleepers who slept at their homes and the findings refer to the natural variations in normal sleep. Further information about the relationship between nocturnal motor activity and sleep quality could be obtained with experimental settings in which interventions like medication or the intentional fragmentation of sleep are used together with the standard sleep polygraphy and the SCSB.

Simple motility based recordings have been suggested as especially useful when data of multiple nights are needed, but the present results also indicate the importance of repeated recordings under many circumstances. The absence of FNE in movements does not necessarily imply the adequacy of single-night motor activity studies for the reliable evaluation of sleep quality. Both the great inter-individual differences in motility and the unsystematic but remarkable variation within subjects suggest that, at least as regards small samples of subjects, very much cannot be inferred from a single-night movement recording. Consequently, if motility is intended to be used as an objective indicator of sleep quality more than one recording night is often advisable in order to know the individual motor baseline.

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