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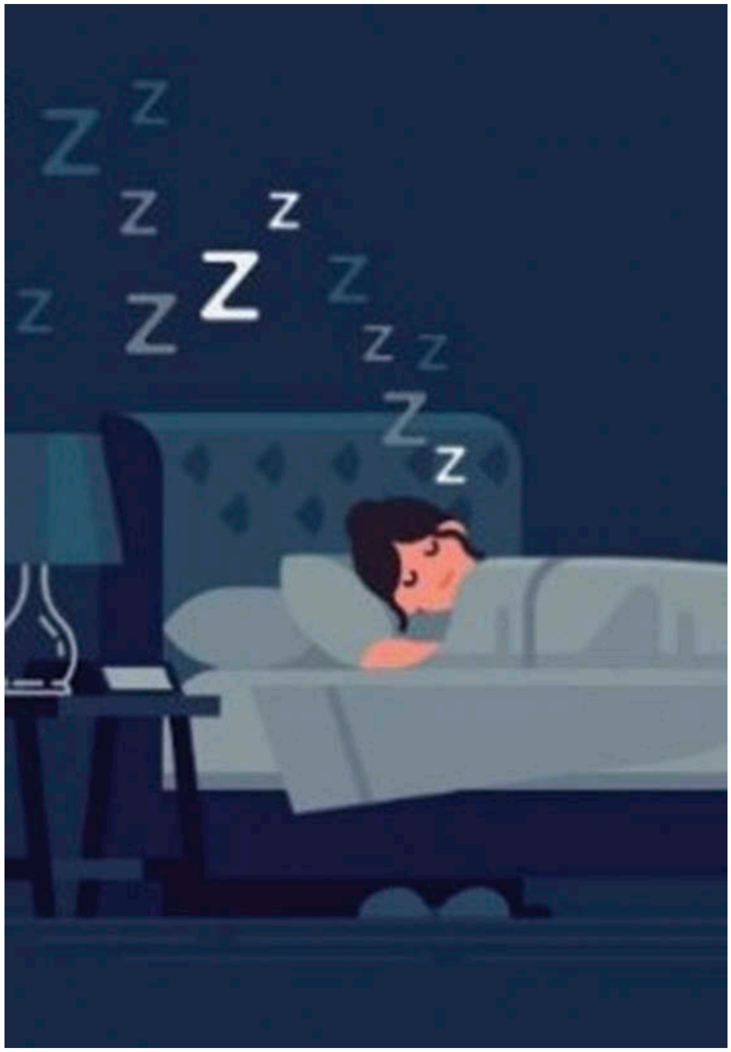

HEALTH PSYCHOLOGY | RESEARCH ARTICLE

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Determinants of self-reported sleep quality in healthy sleepers and patients

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Abstract: A clear clarification of which objective variables are predictive of the subjective sleep experience, and furthermore, which variables of the subjective sleep variables are an adequate representation of the sleep quality score are missing. This may lead to people not identifying possible sleep problems or to people who feel misunderstood when the problem is not objectively observed. Data from the SIESTA database were used, which consists of two consecutive nights of polysomnography and includes subjective data of 156 healthy persons and 95 patients (age range 20–95). Among other things, the strongest significant correlations were found when the difference between nights was taken, for instance, between the subscore "Sleep Quality" of the Subjective sleep and awakening questionnaire (SSA-1) and total sleep time ($r = .423$, $p < .001$). For the mental disorder group, stronger correlations were observed between the absolute sleep measurements of night 1 and SSA-1 (wake time after sleep onset: $r = .732$, $p < .001$). The subscore "Sleep Quality" was sufficient as a representative for the subjective sleep quality score. Our findings indicate that intra-individual variability plays a role and to enhance the insight more nights are needed when investigating the association between subjective sleep quality and objective sleep measurements.

ABOUT THE AUTHOR

Maaike Goelema started her professional career as a PhD student at the Eindhoven University of Technology. The PhD project was performed at the User Centered Engineering research group of the faculty of Industrial design in collaboration with Philips Research. The topic of her PhD project was "Perceived sleep quality in a personal health monitoring context." Maaike obtained her PhD under the supervision of Professor Panos Markopoulos and Reinder Haakma in 2018. Tim Leufkens is a sleep researcher within Royal Philips. Maaike is currently employed at a mental healthcare company treating patients with various mental illnesses.

PUBLIC INTEREST STATEMENT

The importance of a good night's sleep is increasingly known to the general public. More and more people want to monitor their sleep to find out how they have slept, especially people who are worried about their sleep. Until now, low to medium correlations were found between objective sleep measures and subjective sleep quality. This may lead on the one hand to people not identifying a possible sleep problem subjectively, in the case of an absence of an objective sleep measurement. On the other hand, this may lead to people who subjectively report having a sleep problem becoming frustrated and distressed as their problem is not objectively observed. A reason for the low correlation could be on how the association has been analyzed so far. This article studies with an explorative analysis aforementioned relationship from a different angle. Differences between nights was a great predictor for the subjective sleep quality, meaning that more research studies are needed that investigate aforementioned relationship in a longitudinal way.

Subjects: Health Psychology; Quality of Life; Behavioral Medicine

Keywords: sleep measurements; subjective sleep quality; sleep variability

1. Introduction

It has been frequently shown that in both healthy individuals as people suffering from mental and somatic diseases that objective sleep measurements are, at best, weakly to moderately correlated with subjective sleep quality ratings (Åkerstedt, Hume, Minors, & Waterhouse, 1994a; Åkerstedt, Hume, Minors, & Waterhouse, 1997; Armitage, Trivedi, Hoffmann, & Rush, 1997; O'Donnell et al., 2009; Riedel & Lichstein, 1998; Rosipal, Lewandowski, & Dorffner, 2013; Rotenberg, Indursky, Kayumov, Sirota, & Melamed, 2000). This may lead on the one hand to people not identifying a possible sleep problem subjectively in the case of an absence of an objective sleep measurement. On the other hand, this may lead to people who subjectively report having a sleep problem becoming frustrated and distressed as their problem is not objectively observed.

A reason for not finding high correlations between objective and subjective sleep measures may be that the majority of previous studies are cross-sectional and thus do not capture the variations between nights within individuals (Argyropoulos et al., 2003; O'Donnell et al., 2009; Riedel & Lichstein, 1998; Westerlund, Lagerros, Kecklund, Axelsson, & Åkerstedt, 2016). For instance, O'Donnell et al. (2009) found only an association between subjective sleep quality and light sleep, but not with total sleep time, wake time after sleep onset or sleep onset latency (the length of time it takes from lying down for the night until sleep onset). In contrast, Åkerstedt et al. (1997) have not found an association between subjective sleep quality and light sleep but observed a correlation between deep sleep and total sleep time. They also did not find a correlation between subjective sleep quality and sleep efficiency (the number of minutes of sleep divided by the number of minutes in bed) or wake time after sleep onset. In another study of Åkerstedt et al. (1994a), a correlation was observed between subjective sleep quality and sleep efficiency but subjective sleep quality was not related to the sleep stages. Overall, higher correlations have been found between subjective evaluation of sleep and irregular sleep schedules. For instance, when participants were allowed to sleep for 6 h and a 1-h nap subjective ratings of sleep quality were more strongly associated with objective sleep parameters than when they were allowed to have 8 nocturnal hours straight (Åkerstedt et al., 1994a; Åkerstedt et al., 1997; O'Donnell et al., 2009).

Higher correlations between objective and subjective measures were found in Lewandowski, Rosipal, and Dorffner (2012) and Rosipal et al. (2013). Both studies used objective measures derived from a probabilistic sleep model mainly focusing on microstructure elements of sleep. Although both studies provide a valuable new approach of continuous sleep representation, current clinical practice still focuses on conventional R&K scoring (Rechtschaffen & Kales, 1968) or its updated version (Iber, Ancoli-Israel, Chesson, & Quan, 2007). In addition and contrasting to the aforementioned studies, the present study has a primary interest in night-to-night variations in sleep parameters.

As far as we know only Riedel and Lichstein (1998) and Saletu et al. (2005) tried to predict the subjective sleep quality based on the difference between the objective sleep measurements of two nights. Riedel and Lichstein (1998) investigated the relationship between objective and subjective sleep ratings in insomniacs by subtracting the polysomnography (PSG) measures of the first night from those of the second night and conducted a linear regression analysis to predict the subjective sleep satisfaction of the second night. Depth of sleep and sleep latency were found to moderately correlate with subjective sleep satisfaction of the second night. The results were found in a specific subsample of older individuals suffering from insomnia, i.e. without somatic or psychiatric comorbidities. Rosipal et al. (2013) conducted analyses using the same data set as the present study and found that sleep efficiency correlated most with scores on self-rating questionnaire for sleep and awakening quality. However, it was not revealed whether specific subscores of the questionnaire correlated with objective sleep parameters and whether per night correlations were investigated as well. Moreover, correlations of day-to-day changes between subjective and objective sleep in different patient populations appeared not to be examined.

A limited number of studies have examined the relationship between objective and subjective sleep measurements in patient populations, leading to divergent outcomes. For example, Armitage et al. (1997) did not find correlations between subjective sleep quality and sleep efficiency, wake time after sleep onset, light sleep (in this phase the sleep starts, but it is still very light. You no longer wake up from every sound, but you can easily be awakened), deep sleep (or slow-wave sleep, in this phase respiration and heart rate drop to the lowest rhythm. From this phase it is hard to wake someone up.) or sleep onset latency in depressed patients. Another study found only a positive correlation between slow wave sleep (SWS) and the subjective estimation of sleep duration in depressed patients (Rotenberg et al., 2000). A subjective sleep quality rating was not included in the study.

Another reason why objective measurements until now have not been found to correlate highly with subjective sleep quality may be due to the versatile use of the term sleep quality, as discussed by Krystal and Edinger (2008). One conclusion the authors postulated is: "The term 'sleep quality' is not a result of the amount or distribution of sleep and wakefulness but rather a result of variations in the experience of sleep itself." Some studies make a distinction between sleep quality and sleep duration, others take sleep duration as part of the subjective sleep quality. Moreover, some questionnaires ask about awakening quality, such as being refreshed, as part of the overall sleep quality index, others take these as two different subscores. Additionally, there is no standardized questionnaire available to assess subjective sleep quality. The sleep quality indices used differ in the number of questions. When an unambiguous term of sleep quality is operationalized (objectively as well as subjectively), it will benefit future research as each study can utilize the same term and definition.

The aim of the present study was to explore whether night to night changes in objective sleep measures are stronger correlated with subjective evaluations of sleep than when correlating absolute values of one night only. We expect that variations between nights of objective and subjective sleep measurements may explain a greater extent of the relationship between objective sleep variables and perceived sleep quality. Moreover, this is the first study that also conducted such a comparison in various patient samples. In addition, with this exploratory study we want to contribute to the existing literature to examine with a large study sample whether a better relationship is found when using the total score, a subscore or a single question of a sleep quality questionnaire as representative of the subjective sleep quality.

2. Participants and methods

To determine the association between subjective and objective sleep measurements, data from the Siesta project were used (Klösch et al., 2001). In this data set, two nights of PSG measures were collected that we could use for valid objective sleep measures; for that reason, it was considered more efficient to reuse the Siesta data set rather than collect new data. The now completed Siesta project aimed to "conduct extensive research on the development and evaluation of advanced methods for sleep analysis and creating a normative database of healthy and sleep-disturbed patients" (Klösch et al., 2001). The Siesta project was supported by the European Commission and was carried out in several countries around Europe. In short, at the beginning of the study participants signed an informed consent form and did an entrance examination, which consisted of a physical examination and a medical screening. For 2 weeks, participants wore a wrist actigraph device and went to a sleep laboratory for two consecutive nights (night 7 and night 8 of wearing the actigraph device) during which PSG were acquired. During the two nights in the sleep laboratory, an evening and a morning protocol were implemented that included neuropsychological tests and questionnaires asking about their daily events and sleeping habits. For the whole study period, participants filled out a subjective sleep and awakening quality questionnaire each morning. This article focuses solely on the two consecutive nights in the sleep laboratory, and here refers to them as night 1 and night 2.

2.1. Measurements

For this study, the subjective sleep and awakening questionnaire (SSA) was used to determine the subjective sleep quality every morning (Saletu, Wessely, Grünberger, & Schultes, 1987). The SSA consists of 27 questions, divided into three parts: sleep quality (SSA-1), awakening quality (SSA-2) and somatic complaints (SSA-3) (Table 1). The question "Did you sleep well?" (part of the sleep quality subscore) was also used in the analysis, referred to as "sleep well." A total score can be calculated from the three parts, but a subscore of each part separately can be calculated as well. The total score ranges between 20 and 80, and higher scores indicate worse sleep quality.

For applying the PSG, 16 EEG channels were used (Fp1, Fp2, O1, O2, O3, C4, C3, Fz, Cz, Pz, F3, P3, T3, F4, P4, T4). In addition, EOG (Electro-oculogram), EMG (Electromyogram) and ECG (Electrocardiogram) were attached at the appropriate places. The polygraphic recording started at the normal bedtimes of the participants, and they wore the PSG until the time they would normally wake up. The PSG recordings were analyzed in 30-s epochs based on standardized criteria (Rechtschaffen & Kales, 1968). The following parameters were derived from the PSG: *time in bed* (TIB), *total sleep time* (TST), *sleep efficiency* (SE) (in percentages), *sleep onset latency* (SOL), *wake time after sleep onset* (WASO), *total wake time* (TWT), number of awakenings (NAW), total time in sleep stage 1/stage 2/stage 3/stage 4/REM/SWS (Stage 1) (Stage 2) (Stage 3) (Stage 4) (REM) (SWS), all reported in minutes unless stated otherwise.

2.2. Participants

Our analysis was based on data of 156 healthy participants, 14 Parkinson patients, 18 general anxiety disorder, 8 with depressive disorder, 5 periodic limb movement disorder and 50 sleep apnea patients. For analysis purposes, a mental disorder group was created consisting of the general anxiety disorder and the depressive disorder patients ($N = 26$) and a somatic disorder group was made including the periodic limb movement disorder, sleep apnea and Parkinson patients ($N = 69$) (all patients: $N = 95$). The healthy control group was created based on the following inclusion criteria: not diagnosed with a medical disorder interfering with the aim of the study, a Mini Mental State Examination score ≥25 (Folstein, Folstein, & McHugh, 1975), a Self-Rating Anxiety Scale score <33 (Zung, 1971), a Self-Rating Depression Scale score <35 (Zung, 1965), a Pittsburgh Sleep Quality Index global score ≤5 (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) and with normal regularity bedtimes (no shift workers). Based on the International Statistical Classification of Diseases and Related Health Problems (ICD-10) (World Health Organization), a classification of the patient groups was made.

2.3. Statistical analyses

The following main hypothesis was formulated: the association between objective sleep parameters and subjective sleep quality score is enhanced when the difference between two nights of

Table 1. Subjective sleep and awakening quality questionnaire

Sleep quality SSA-1	Awakening quality SSA-2	Somatic complaints SSA-3
(1) Did you sleep well? (2) Did you have deep sleep? (3) Did you have difficulties in falling asleep? (4) Did you have difficulties in staying asleep? (5) Did you have bad dreams? (6) Did you have difficulties getting back to sleep? (7) Did you wake up earlier than usual?	8. Did you feel giddy after awakening? 9. Did you feel disorientated? 10. Did you feel tired? 11. Were you in a good mood? 12. Did you feel interested in your surroundings? 13. Did you feel slowed down? 14. Was your attention/ concentration reduced? 15. Did you feel refreshed and rested?	16. Any nausea after awakening? 17. Any headache? 18. Dryness of your mouth? 19. Any dizziness? 20. In coordination of movements?

measurements is applied compared to taking the measurements of a single night. In addition, we expect that this relationship is also visible in other patient populations as the previous night influences the present night greatly. On an explanatory note, we investigated whether asking only the single question, the subscore or the overall sleep quality score is strongly related to the objective sleep measurements.

Before conducting correlation analyses, the data were checked for violations of the assumptions of this statistical method. The analyses were performed on persons with data on the subjective side as well as on the objective side, leaving a total of 158 healthy controls and 96 patients. However, two subjects (one healthy control and one Parkinson patient) were excluded because of very low total sleep time (less than 84 min) on one of the PSG nights. Analyses were carried out on the remaining 157 healthy persons and 95 patients. Since not every variable in this data set was normally distributed, Spearman correlations were performed.

The variables that represent the difference between the nights were computed. This was done by extracting the sleep parameters of night 1 from night 2, for example, wake after sleep onset night 2 – wake time after sleep onset night 1 = wake time after sleep onset_ difference. Differences were also calculated for the sleep quality subscore (SSA-1) of the SSA questionnaire and its total score, as well as the single question "Did you sleep well?". These variables were taken as indices of the subjective sleep quality. Because of the considered large number of correlations, the Bonferroni correction was applied as such reported associations were significant at a two-tailed p-value of ≤ .001.

3. Results

3.1. Healthy controls

The characteristics of the healthy controls are listed in Table 2. The percentage of men and women was equally divided and the average age in this study population was 52 years (SD = 9.7).

Table 2. Characteristics of study sample (healthy controls n = 156 and all patients n = 95) and descriptive statistics of the sleep variables

Characteristics	Healthy controls		All patients	
Age, mean (SD)	51.5 (9.7)		51.6 (12.2)	
Female gender, *N* (%)	85 (54.1)		24 (25)	
Subjective sleep parameters	**Night 1**	**Night 2**	**Night 1**	**Night 2**
SSA total score, median (IQR)	29 (7)	28 (6)	39 (11.75)	34 (12)
SSA-1 subjective sleep quality, median (IQR)	12 (5)	10 (4)	15.5 (8)	12 (7.75)
Objective sleep parameters				
Total time in bed, mean (SD)	469.5 (29.5)	471.1 (30.6)	475.5 (29.1)	480.2 (34.5)
Total sleep time, mean (SD)	362 (65.1)	396.8 (49.4)	360.2 (79.4)	396.5 (67.7)
Sleep efficiency, mean (SD) %	77.1 (13)	84.3 (9.5)	75.6 (15.4)	82.6 (12.8)
Sleep onset latency, mean (SD)	22.8 (20.7)	18.1 (17)	21 (25.9)	13.8 (11.3)
Wake time after sleep onset, mean (SD)	75.8 (52.7)	50.6 (39.2)	83.5 (57.6)	59.4 (50.9)
Number of awakenings, mean (SD)	25.5 (12.3)	21.8 (10.7)	34 (20.8)	28.8 (19.4)
Total wake time, mean (SD)	107.6 (62.4)	74.3 (45.5)	115.3 (72.2)	83.7 (61.3)
Sleep stage 1, mean (SD)	43.5 (22.3)	40.7 (21.3)	62.4 (37.1)	60.7 (42.3)
Sleep stage 2, mean (SD)	202.1 (48.4)	215.6 (44.3)	197.3 (60.3)	208.7 (53)
Sleep stage 3, mean (SD)	28 (14.6)	33.2 (16.1)	25.6 (14.6)	30.7 (17.8)
Sleep stage 4, mean (SD)	25.7 (25.1)	28.3 (25.1)	13.1 (25.1)	19.8 (23.1)
REM stage, mean (SD)	62.7 (24.6)	79 (25.9)	61.8 (29.6)	76.6 (28.6)
Slow wave sleep, mean (SD)	53.8 (30.1)	61.5 (30.8)	38.7 (30)	50.5 (31.4)

Note: All sleep measurements are reported in minutes, unless stated otherwise.

Participants slept an average of 6 h and 2 min (SD = 1 h 5 min) on the first night and an average of 6 h and 37 min (SD = 49 min) on the second night. Also, 26% of the healthy controls indicated they had not slept well or slept only slightly well during the first night of sleep and for the second night 10% of the healthy controls did not sleep (slightly) well, based on the single question "How well did you sleep?". A paired-sample *t*-test was conducted to determine whether there were significant differences between the two nights. A significant increase in the mean sleep efficiency (SE) of the second night compared to the mean of the first night was found ($t(156) = -7.202$, $p < .001$). Similarly, the subjective sleep quality (SSA-1) was significantly lower after the second night than after the first night ($t(156) = -4.544$, $p < .001$).

3.2. Patients

In Table 2, the characteristics of the patient sample are displayed. The percentage of women is lower in this sample compared to the healthy controls. However, the average age of 52 years is identical. The total sleep time during the first night was 6 h, and the total amount of sleep time during the second night was 6 h and 36 min. Also, 68% reported they did not sleep well or slept slightly well during the first night and 33% of the patients indicated they had not slept well or slightly well on the second night. This was also confirmed by the paired-sample *t*-test where the sleep efficiency was lower after the first night than after the second night. Also, the subjective sleep quality score was higher after the first night compared to the second night (sleep efficiency ($t(95) = -.5.108$, $p < .001$) and sleep quality ($t(95) = 4.390$, $p < .001$)).

3.3. Correlations healthy controls

3.3.1. First night

Significant correlations were found between TST, WASO, SE, NAW, REM, Stage 2 and TWT and SSA-1 (Table 3). This means that, for instance, less minutes spent in REM is associated with an increase in the SSA-1 (SSA-1 with REM $r = -.33$, $p < .001$). Around the same level of correlations were found between SSA total score and objective sleep parameters. Moreover, slightly less high correlations were observed with the sleep well question and TST, WASO, TWT and REM.

3.3.2. Second night

The lowest correlations were found when taking the absolute parameters of the second night (Table 4). Noteworthy is that stronger significant correlations were observed between NAW and SSA-1 of the second night ($r = .32$, $p < .001$) compared to the association between NAW and SSA-1 of the first night ($r = .27$, $p = .001$).

3.3.3. Differences between nights

The highest correlations were found when taking the difference of the nights: subjective sleep quality (SSA-1) with TWT ($r = .42$, $p < .001$) and subjective sleep quality (SSA-1) with SE ($r = .42$, $p < .001$) (Table 5). Moreover, significant correlations were found between ΔTST, ΔWASO and the Δtotal score of the SSA (Table 5).

Overall, higher correlations were found when taking the sleep quality subscore (SSA-1) to associated with objective sleep measures (Tables 3–5). Additionally, the question "Did you sleep well?" correlated with some of the absolute objective sleep parameters and with some of the delta objective sleep measures, although fewer and weaker correlations were found compared to the SSA-1. The total score of the SSA had stronger correlations with the absolute parameters of the two nights than with the parameters of the difference between nights.

There were no correlations observed between awakening quality (SSA-2) and the absolute objective sleep measures from night 1 and night 2. Somatic complaints subscore (SSA-3) was associated with TST, WASO, SE, TWT and Stage 2 with an *r* ranging from .29 till .34 based on night 1. Fewer correlations were found between SSA-3 and the objective sleep measurements of night 2 (SE: $r = -.288$, $p < .001$; WASO: $r = .327$, $p < .001$; TWT: $r = .306$, $p < .001$).

Table 3. The association between objective and subjective sleep parameters based on the first night for healthy controls

	Sleep well		SSA-1		SSA total score	
	r	*p*	*r*	*p*	*r*	*p*
TIB	.03	.74	.05	.51	.02	.77
TST	.31	**<.001**	−.32	**<.001**	−.34	**<.001**
SE	.32	**<.001**	−.36	**<.001**	−.37	**<.001**
WASO	.30	**<.001**	.41	**< .001**	.41	**<.001**
SOL	.09	.29	.04	.60	.01	.91
NAW	.15	.06	.27	**.001**	.22	.006*
TWT	.32	**<.001**	.36	**<.001**	.36	**<.001**
Stage 1	−.07	.40	.04	.60	.04	.64
Stage 2	−.21	.008*	−.24	.003*	−.29	**<.001**
Stage 3	−.18	.03	−.15	.06	−.13	.10
Stage 4	−.02	.84	−.04	.60	−.03	.76
REM	−.28	**<.001**	−.33	**<.001**	−.28	**<.001**
SWS	−.08	.35	−.08	.32	−.05	.51

Notes: Sleep well = SSA question: “Did you sleep well?”; SSA-1 = subjective sleep quality subscore; TIB = (total) time in bed; TST = total sleep time; SE = sleep efficiency; SOL = sleep onset latency; NAW = number of awakenings during the night; TWT = total wake time; stage 1/stage 2/stage 3/stage 4/rapid eye movement (REM)/ slow wave sleep (SWS) = total time in a particular sleep stage.
Significant *p*-values are shown in bold.
*Correlations that are significant but between >.001 and ≤.01.

Table 4. The association between objective and subjective sleep parameters based on the second night for healthy controls

	Sleep well		SSA-1		SSA total score	
	r	*p*	*r*	*p*	*r*	*p*
TIB	.18	.03	.06	.47	.06	.49
TST	−.08	.31	−.28	**<.001**	−.25	.002*
SE	−.21	.009*	−.34	**<.001**	−.29	**<.001**
WASO	.23	.005*	.34	**<.001**	.33	**<.001**
SOL	.05	.51	.14	.08	.05	.50
NAW	.28	**<.001**	.32	**<.001**	.29	**<.001**
TWT	.22	.006*	.35	**<.001**	.30	**<.001**
Stage 1	.004	.96	.09	.28	.09	.26
Stage 2	.05	.57	−.15	.06	−.14	.07
Stage 3	−.09	.25	−.03	.68	−.01	.92
Stage 4	−.05	.52	−.03	.69	−.04	.59
REM	−.05	.57	−.19	.02	−.17	.03
SWS	−.09	.25	−.05	.51	−.04	.61

Notes: Sleep well = SSA question: “Did you sleep well?”; SSA-1 = subjective sleep quality subscore; TIB = (total) time in bed; TST = total sleep time; SE = sleep efficiency; SOL = sleep onset latency; NAW = number of awakenings during the night; TWT = total wake time; stage 1/stage 2/stage 3/stage 4/rapid eye movement (REM)/ slow wave sleep (SWS) = total time in a particular sleep stage.
Significant *p*-values are shown in bold.
*Correlations that are significant but between >.001 and ≤.01.

Table 5. The association between objective and subjective sleep parameters of the difference between the nights for healthy controls

	Sleep well		SSA-1		SSA total score	
	r	***p***	***r***	***p***	***r***	***p***
TIB	.16	.04	.14	.08	.18	.03
TST	−.21	.009*	−.28	**.001**	−.22	.007*
SE	−.31	**<.001**	−.42	**<.001**	−.35	**<.001**
WASO	.24	.003*	.34	**<.001**	.29	**<.001**
SOL	.11	.16	.13	.10	.13	.12
NAW	.11	.16	.21	.010*	.18	.03
TWT	.32	**<.001**	.42	**<.001**	.37	**<.001**
Stage 1	.05	.51	.10	.20	.13	.11
Stage 2	−.10	.21	−.25	.002*	−.19	.02
Stage 3	−.05	.52	−.05	.51	−.11	.19
Stage 4	−.15	.07	−.09	.25	−.10	.22
REM	−.28	**.001**	−.23	.003*	−.19	.019
SWS	−.11	.18	−.08	.32	−.11	.19

Notes: Sleep well = SSA question: "Did you sleep well?"; SSA-1 = subjective sleep quality subscore; TIB = (total) time in bed; TST = total sleep time; SE = sleep efficiency; SOL = sleep onset latency; NAW = number of awakenings during the night; TWT = total wake time; stage 1/stage 2/stage 3/stage 4/rapid eye movement (REM)/ slow wave sleep (SWS) = total time in a particular sleep stage.
Significant *p*-values are shown in bold.
*Correlations that are significant but between >.001 and ≤.01.

3.4. Correlations patients groups

Table 6 displays the associations between the objective sleep parameters and subjective sleep quality subscore for various patient groups. The highest correlations were also observed between the difference of the nights of the objective sleep measurements and the subjective sleep quality subscore, except for the mental disorder group. For the mental disorder group, higher correlations were observed using the absolute parameters of the separate nights: for example, WASO with SSA-1, night 1, $r = .732$, $p < .001$ and REM, night 2, $r = .525$, $p < .001$. In the overall patient group, a correlation was observed between Stage 2 and the sleep quality (SSA-1) ($r = -.390$, $p < .001$). For the somatic disorder group, overall high correlations were found between TST, TIB, SE, WASO and TWT and sleep quality (SSA-1) when taking the difference between the nights (Table 6).

In order to determine whether stronger correlations between objective and subjective sleep measures were due to higher stability of a sleep measure (irrespective of objectivity or subjectivity) across nights, the standard deviations (SDs) of the variable TWT and the sleep quality, and their correlations are compared and displayed in Table 7. Consequently, the SD of TWT night 2 was lower than the SD of TWT in night 1 or in the difference between the nights in almost all groups. Additionally, the SD of the sleep quality variable was the lowest in night 2 for the healthy controls and the somatic disorder group. In the mental disorder group, the SD of sleep quality were a lot closer to each other and the SD of the sleep quality of night 2 was the largest.

4. Discussion

This is the first study that investigated the association between objective sleep measurements and subjective sleep quality by exploring different methods (e.g. delta between nights vs. one night and different subscores of subjective sleep quality) to assess the aforementioned association and compare these in various patient sample, as this has not been done before. In most of the study samples, moderate to high correlations were found when taking the difference between nights. For healthy controls, the correlations of the first night were almost identical to the correlations of the

Table 6. The association between objective and subjective sleep quality (SSA-1) with the difference between the nights, displayed for all patients and various patient groups

Sleep parameters	All patients (*N* = 95)		Mental disorder group (*N* = 26)		Somatic disorder group (*N* = 69)	
	r	*p*	*r*	*p*	*r*	*p*
TST	−.47	**<.001**	−.28	.17	−.51	**<.001**
TIB	.25	.02	−.07	.74	.44	**<.001**
SE	−.54	**<.001**	−.33	.10	−.60	**<.001**
WASO	.47	**<.001**	.33	.10	.50	**<.001**
TWT	.54	**<.001**	.34	.09	.61	<.001
SOL	.36	**<.001**	.31	.12	.38	.001
NAW	.24	.02	.17	.42	.26	.030
Stage 1	−.03	.80	.15	.46	−.05	.692
Stage 2	−.39	**<.001**	−.52	.007*	−.32	.007*
Stage 3	−.03	.79	−.01	.97	−.04	.766
Stage 4	−.05	.65	.08	.70	−.01	.437
REM	−.21	.04	−.18	.38	−.19	.119
SWS	−.04	.71	−.07	.75	−.05	.667

Notes: TIB = (total) time in bed; TST = total sleep time; SE = sleep efficiency; SOL = sleep onset latency; NAW = number of awakenings during the night; TWT = total wake time; stage 1/stage 2/stage 3/stage 4/rapid eye movement (REM)/ slow wave sleep (SWS) = total time in a particular sleep stage.
Significant *p*-values are shown in bold.
*Correlations that are significant but between >.001 and ≤.01.

Table 7. Displayed are the standard deviations and the zero-order correlations of the variables SSA-1 and TWT for each study population and each method separately

	Healthy controls	All patients	Mental disorder group	Somatic disorder group
Night 1				
SD SSA-1	3.97	4.87	5.54	4.42
SD TWT	60.4	71.52	78.96	69.1
r =	.36	.34	.50	.26
Night 2				
SD SSA-1	3.21	5.1	6.1	4.16
SD TWT	45.61	51.64	50.15	52.49
r =	.35	.33	.41	.27
Difference between nights				
SD SSA-1	4.23	4.94	5.7	4.61
SD TWT	57.13	60.29	54.42	62.73
r =	.42	.55	.40 n.s.	.61

Notes: SSA-1 = subjective sleep quality subscore; TWT = total wake time; SD = standard deviation; *r* = correlation coefficient; n.s. = not significant.

difference between nights. However, for the somatic disorder group the correlations of the absolute measurements of each night separately were distinctly lower than the correlations of the difference between nights. On the contrary, for the mental disorder group higher correlations were found with the absolute measurements of the nights.

This difference in findings between the healthy controls and the patients groups led us to examine whether the results were due to a larger variation in some of the variables. There was clearly a link between the height of the SD of the variables and the height of the correlation found between the variables. This is in line with Krystal and Edinger (2008), who noted that the variation between nights is indicative of the sleep quality. Instead of seeing it as a linear relationship, maybe the association between objective and subjective sleep parameters is only shown when the most extreme values are present. For example, with sleep duration, only a short or long sleep duration correlates well with subjective sleep quality. Moreover, this could mean that regularity measures such as SD are better predictors of the subjective sleep experience. This should be better investigated in longitudinal studies.

However, in the somatic disorder group, low correlations were observed in the first night, regardless of the first night effect. This is probably due to a high SD in the objective sleep measurements but a relatively small SD on the subjective measurement, meaning that the ratings of the participants were not that distinctive regardless of the large differences in the objective measurements, resulting in a low correlation. In contrast, the mental disorder group had high correlations in the absolute measures of the nights, indicating that probably those persons rated accurately how they have slept, making the analysis of the difference between nights less meaningful. Alternatively, the results may also be due to the small sample size of the mental disorder group (N = 26).

It appeared that the variables that represent sleep continuity, for example, wake time and sleep efficiency, were also correlated the strongest with the subjective sleep quality subscore. This is in line with Åkerstedt et al. (1997). Events that happen during the night and that people remember the next morning contribute the most to their assessment of their subjective sleep experience. For instance, when a higher delta between the scores of TWT of the nights was observed, also a larger difference between the subjective sleep quality scores was found. In other words, the range of the difference in the objective sleep variables was around the same as the range of difference in the subjective sleep quality for most healthy participants. Regarding the sleep stages, Stage 2 and REM had the strongest association with the subjective sleep quality subscore, but to a lesser extent compared to the sleep continuity variables in the healthy controls. These findings are in line with previous research (O'Donnell et al., 2009; Saletu, 1975).

Lastly, the association was best shown when using the subjective sleep quality subscore instead of the total score of the SSA. When analyzing the association with the single question "Did you sleep well?" the correlations were less strong. This means that a couple of questions about last night are necessary as a representative for the subjective sleep quality score. In our study, these included the following themes: general rating of sleep quality, falling and staying asleep, the amount of deep sleep, ease of getting back to sleep and early awakening. Åkerstedt, Hume, Minors, and Waterhouse (1994b) found similar outcomes and made a sleep quality index based on the following questions: sleep quality, calm sleep, ease of falling asleep and ability to sleep throughout the time allotted. Harvey, Stinson, Whitaker, Moskovitz, and Virk (2008) also examined the subjective sleep quality, but among individuals with and without insomnia and did not include PSG measurements of sleep. They used as a method an interview and speak freely procedure. The normal sleepers rated the following five questions as the most important factors for judging sleep quality: whether you get enough sleep, how tired you feel throughout the day, how rested you feel when waking up, feeling restored on waking and feeling alert throughout the day. In the present study, the correlations between awakening quality (SSA-2) and the objective measures were lower than the correlations with sleep quality (SSA-1).

Arguably in depressed patients, sleep disturbances can consist of both biological and cognitive elements (Argyropoulos et al., 2003; Lee et al., 1993). This means that improvements in the subjective sleep quality may represent changes in their general way of thinking, improved by, for example, cognitive behavioral therapy for treating their depression. This change in subjective sleep quality may be found regardless of enhancements in PSG measurements or biological changes. Stated is then that subjective and objective measurements may demonstrate two different processes and not be directly related (Argyropoulos et al., 2003). However, with regards to normal sleepers, one needs to be cognizant that when answering, for example, the question: "How well did you sleep?", individual differences and various frames of reference are used. At the same time, errors and malfunctions on the objective side cause noise in the aforementioned association.

This is one of the few studies that investigated the association between objective and subjective sleep measurements in a large study sample. The outcomes for healthy sleepers in this study were also compared to different patient groups. Additionally, two nights of PSG were obtained, as normally with such large study samples only actigraphy is used. A limitation of the study is that the two nights of PSG are executed in the laboratory. Ideally, testing should be done at home to have more representative "normal" nights. As is previously mentioned, more nights are required to reveal the variations between nights. In this study, there is a "first night effect" since significant differences were found between the objective and subjective sleep measurements, which may interfere with the results. However, due to the "first night effect," we were able to show that taking the difference between the nights of the measurements is more informative than the absolute measures of each night separately. People will experience throughout their life good and bad nights of sleep. Recently studies with a longitudinal design investigated various relationships between objective sleep measurements and sleepiness, sleep quality and stress (Åkerstedt, Axelsson, Lekander, Orsini, & Kecklund, 2013; Åkerstedt et al., 2012; Doane & Thurston, 2014; Garde, Albertsen, Persson, Hansen, & Rugulies, 2012). Åkerstedt et al. (2012) investigated the relationship between objective sleep measurements, stress and subjective sleep quality. They found that stress at bedtime was the main factor that predicted the subjective sleep quality the next morning. Still, most of the studies did not examine the relationship between objective and subjective sleep quality specifically and did not take into account the variation on a subjective sleep quality level. Another limitation of the current study is that other parameters that might influence sleep were not taken into account, such as exercise, caffeine intake and stress (Hall et al., 2004; Roehrs & Roth, 2008; Youngstedt, 2005).

5. Conclusions

This is the first study to explore the association between objective and subjective sleep measurements taking into account the difference between nights in normal sleepers and various patient samples. A stronger association was evident when conducting the analyses with the delta of two nights. This result shows that when examining multiple nights this could result in more insight in the subjective sleep experience. As a consequence, more longitudinal studies should be performed to collect data that is more suitable for these kinds of purposes. The enhanced correlation in the analysis with the difference between measurements of the two nights was also observed in the mental disease population but not for the other patient samples. In addition, it was concluded that a standardized and well-accepted subjective sleep quality index is necessary that should contain questions around continuity and deepness of sleep, and an overall sleep quality rating, to improve the current assessment of subjective sleep quality. Intra-individual variability plays a role, and to enhance the insight, more nights are needed to investigate the association between subjective sleep quality and objective sleep measurements.

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