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Comparison of objective and subjective sleep parameters in patients with bipolar disorder in both euthymic and residual symptomatic periods

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ABSTRACT

Background: Sleep disturbance is a core feature of bipolar disorder; hence, sleep must be accurately assessed in patients with bipolar disorder. Subjective sleep assessment tools such as sleep diary and questionnaires are often used clinically for assessing sleep in these patients. However, the insight into whether these tools are as accurate as objective tools, such as actigraphy, remains controversial.

Methods: This cross-sectional study included 164 outpatients with a diagnosis of bipolar disorder, including patients who had euthymic and residual symptomatic periods. Objective sleep assessment was conducted prospectively using actigraphy for 7 consecutive days, whereas subjective sleep assessment was conducted prospectively using a sleep diary.

Results: The correlations were high and moderate between sleep diary and actigraphy when assessing the total sleep time and sleep onset latency, respectively ($r = 0.81$ and 0.47). These correlations remained significant after correction for multiple testing (both $p < 0.001$) and in both euthymic and residual symptomatic states (total sleep time: $r = 0.86$ and 0.77; sleep onset latency: $r = 0.51$ and 0.40, respectively). The median (interquartile ranges) of the percentage difference (sleep diary parameters minus actigraphy parameters divided by actigraphy parameter) in the total sleep time was relatively small (6.2% [−0.2% to 13.6%]).

Conclusions: Total sleep time assessment using a sleep diary could be clinically useful in the absence of actigraphy or polysomnography.

1. Introduction

Sleep disturbance is a core feature of bipolar disorder and can occur regardless of whether an affected patient is in a euthymic or symptomatic period (Geoffroy et al., 2015; Harvey, 2008; Ng et al., 2015). In bipolar disorder cases, sleep disturbance is associated with subsequent mood episodes, cognitive abnormalities, and suicidal ideation (Bradley et al., 2020; Gershon et al., 2017; Stange et al., 2016). Therefore, the sleep status of patients with bipolar disorder must be accurately assessed.

Sleep status can be evaluated using various tools, including polysomnography, actigraphy, sleep diaries, and questionnaires. Polysomnography is a widely accepted objective measure of sleep and is the gold standard for exploring sleep disturbance. Actigraphy is also a useful tool for objectively estimating sleep and daily activity patterns (Ancoli-Israel et al., 2003; Sadeh, 2011) and has been validated against polysomnography for several sleep parameters in patients with bipolar disorder (Kaplan et al., 2012). However, considering cost constraints in daily practice, availability, invasiveness, and acceptability to patients, it is difficulties to use these tools for all patients. Therefore, in clinical practice, sleep status in patients with bipolar disorder is often assessed using subjective tools such as sleep diary and questionnaires.

However, the insight into whether these subjective tools are as accurate as objective sleep assessment tools, such as actigraphy, remains controversial. In previous studies, objective sleep assessed by actigraphy significantly correlated with subjective sleep assessed by sleep diary or questionnaire in patients with bipolar disorder (Boudebesse et al., 2014; Gonzalez et al., 2013; Ihler et al., 2020). In contrast, other studies

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revealed no correlation or a marked discrepancy (Harvey et al., 2005; Krishnamurthy et al., 2018; Ritter et al., 2016). However, these previous studies enumerated several limitations that need to be addressed. For instance, the number of bipolar disorder cases collected in a recent study was relatively large (133 patients) (Ihler et al., 2020), whereas that in other previous studies was small (20–39 patients). In addition, the previous studies included only patients with specific conditions, such as euthymic or symptomatic periods. Mood symptoms may be related with the discrepancy between subjective and objective sleep measurements (Gonzalez et al., 2013; Krishnamurthy et al., 2018). However, in the clinical course, patients with bipolar disorder repeatedly experience both euthymic and symptomatic periods (Judd et al., 2002, 2003). Therefore, cases including both euthymic and symptomatic periods must be investigated.

In this cross-sectional study, we examined whether subjective sleep assessment using sleep diary and the Insomnia Severity Index (ISI) questionnaire is as accurate as objective sleep assessment using actigraphy in 164 patients with bipolar disorder, including patients with euthymic and residual symptomatic periods. We hypothesized that prospective assessment of sleep diaries kept by patients with euthymic periods would show strong correlations and little difference between subjective and objective sleep measurements.

2. Methods

2.1. Participants and study protocol

This study included outpatients with bipolar disorder who participated in a study entitled "Association between the Pathology of Bipolar Disorder and Light Exposure in Daily Life (APPLE) cohort study," conducted by two hospitals and two clinics in Japan between August 2017 and October 2019. The study protocol was reported in our previous study (Esaki et al., 2019). Briefly, we included patients aged 18–75 years and diagnosed with bipolar disorder I or II according to the Diagnostic and Statistical Manual of Mental Disorders 5th edition. Conversely, we excluded night-shift workers, people with a serious suicidal risk as judged by a clinician, and those with acute manic, mixed, and depressive episodes (we enrolled patients with only residual symptoms in the present study). Of the 218 outpatients participated in this study, 11 and 43 were excluded because of their inability to wear an actigraph and failure to complete the sleep diary, respectively. Ultimately, we included 164 participants. This study conformed to the ethics committee of Okehazama Hospital in accordance with the Declaration of Helsinki of 1975 revised in 2008. We obtained written informed consent from each participant and registered the study at UMIN-CTR (identifier: UMIN000028239). We assessed the demographic and clinical characteristics of the participants at the clinic and asked them to perform the following at home for 7 consecutive days: (1) recording a sleep diary; (2) wearing an actigraph (Actiwatch Spectrum Plus; Respironics Inc., PA, USA) on the wrist of their nondominant arm for 24 h/day.

2.2. Subjective and objective sleep assessment

Subjective sleep was evaluated retrospectively using the ISI questionnaire and prospectively using a sleep diary. ISI is a self-rated seven-item questionnaire that assesses the severity of the nighttime and daytime components of insomnia (Bastien et al., 2001). We administered ISI at the start of the experimental period to evaluate the severity of the participants' insomnia over the previous week. We defined ISI score $\geq$8 points as insomnia. Furthermore, we asked the participants to record the following four items in sleep diary for 7 consecutive days: (1) bedtime: the time when the participant went to bed with the intention to sleep, excluding the time spent in bed reading books, watching TV, or using a smart phone; (2) sleep onset latency (SOL): the time from bedtime to falling asleep; (3) wake after sleep onset (WASO): the total time of awakening during the night; and (4) rising time: the time when the participant finally got out of bed. They were asked to record their bedtime right before they went to bed and to record their SOL, WASO, and rising time right after they woke up. Then, we calculated the following two sleep parameters from the data recorded in a sleep diary: (1) total sleep time (TST): the total time asleep between bedtime and rising time, deducting the SOL and WASO; and (2) sleep efficiency (SE): the percentage calculated from TST divided by the time between bedtime and rising time.

Meanwhile, objective sleep was measured using actigraphy for 7 consecutive days. The actigraph sampled data for 1 min epochs; a moderate threshold of 40 counts per min indicated that the participants were awake. The accuracy of this threshold setting is similar to that of polysomnography in measuring sleep in patients with bipolar disorder (Kaplan et al., 2012). Time in bed, regardless of whether participants were asleep or awake, was defined according to entries in the sleep diary and not by the actigraphy data. This method has been used in previous studies of patients with bipolar disorder and was used in this study for all participants on all days (Boudebesse et al., 2013; Esaki et al., 2019). The actigraphy sleep data were automatically analyzed with the sleep detection algorithm in the software for the actigraph (Actiware version 6.0.9; Respironics Inc., PA, USA). Moreover, the present study used the following four actigraphy sleep parameters: (1) SOL: the time from bedtime to the start of sleep; (2) WASO: the total time spent awake from sleep start to end; (3) TST: the total time spent asleep from sleep start to end during the main sleep phase, excluding WASO; and (4) SE: the percentage of TST between bedtime and rising time for the main sleep phase.

2.3. Other assessments

Each participant's current depressive or manic status was assessed using the Montgomery–Åsberg Depression Rating Scale (MADRS) and the Young Mania Rating Scale (YMRS) (Montgomery and Asberg, 1979; Young et al., 1978). As recommended by the International Society for Bipolar Disorders Task Force, a MADRS or YMRS score of $<$8 points indicates symptomatic remission of bipolar depression or mania, respectively (Tohen et al., 2009). Thus, this study defined the MADRS or YMRS score of 8 points as the cutoff value and divided the participants into two groups: the euthymic group (MADRS and YMRS score of $<$8 points) and the residual symptomatic group (MADRS or YMRS score of $\geq$8 points). Information on the participant's current psychiatric medications, including lithium, anticonvulsants (lamotrigine, valproate, and carbamazepine), antipsychotics, antidepressants, hypnotics, and anxiolytics, were collected from their clinical records.

2.4. Statistical analyses

We present continuous variables as the median and interquartile range (IQR) and categorical variables as number and percentage. The average values of sleep diary parameters and actigraphy sleep parameters from 7 consecutive measurement days were used for the analysis. In a previous study with the same sample, the weekday and weekend sleep parameters, including sleep duration, SE, SOL, and WASO, did not differ significantly (Esaki et al., 2021). The medians were compared between the dichotomous groups using the Mann–Whitney *U* test. Meanwhile, the categorical data were compared using the chi-square test. The dichotomous groups were compared in terms of the following variables: demographic characteristics (age, gender, married status, education level, and employment status), clinical characteristics (type of bipolar disorder, age at onset of bipolar disorder, duration of illness, and MADRS and YMRS scores), psychiatric medications (lithium, anticonvulsants, antipsychotics, antidepressants, hypnotics, and anxiolytics), subjective sleep parameters (ISI score [total score, difficulty falling asleep, difficulty staying asleep], sleep diary parameters [bedtime, rising time, TST, SE, SOL, and WASO]), and actigraphy (objective) sleep parameters (TST, SE, SOL, and WASO). The correlations between

Table 1
Demographic and clinical characteristics for the euthymic and symptomatic groups.

Variables	All (n = 164)	Euthymic (n = 66)	Residual symptomatic (n = 98)	*p*
Demographic characteristics				
Age, years, median (IQR)	43.0 (33.0–51.0)	45.0 (35.5–55.0)	41.5 (33.0–49.0)	0.16
Gender, female, n	88 (53.7%)	30 (45.5%)	58 (59.2%)	0.08
Married, n	81 (49.4%)	34 (51.5%)	47 (48.0%)	0.65
Education (≥13 years), n	101 (61.6%)	42 (63.6%)	59 (60.2%)	0.65
Employed, n	71 (43.3%)	33 (50.0%)	38 (38.8%)	0.15
Clinical characteristics				
Type of bipolar disorder, bipolar disorder I, n	59 (36.0%)	24 (36.4%)	35 (35.7%)	0.93
Age at bipolar disorder onset, years, median (IQR)	30.0 (22.0–38.0)	31.0 (23.7–39.2)	29.0 (21.5–36.5)	0.22
Duration of illness, years, median (IQR)	10.0 (7.0–16.0)	10.5 (6.0–17.2)	10.0 (7.0–16.0)	0.76
MADRS score, points, median (IQR)	8.0 (3.2–13.7)	3.0 (1.0–5.0)	12.0 (9.0–20.)	<0.01
YMRS score, points, median (IQR)	2.0 (0–5.0)	1.0 (0–2.0)	3.0 (0.7–7.0)	<0.01
Psychiatric medications				
Lithium, n	69 (42.1%)	27 (40.9%)	42 (42.9%)	0.80
Anticonvulsant, n	91 (55.5%)	37 (56.1%)	54 (55.1%)	0.90
Antipsychotic, n	87 (53.0%)	33 (50.0%)	54 (55.1%)	0.52
Antidepressant, n	54 (32.9%)	26 (39.4%)	28 (28.6%)	0.14
Hypnotic, n	104 (63.4%)	41 (62.1%)	63 (64.3%)	0.77
Anxiolytic, n	24 (14.6%)	8 (12.1%)	16 (16.3%)	0.45
Subjective sleep parameters				
ISI (retrospective parameters)				
Total score, points, median (IQR)	11.0 (7.0–15.0)	7.0 (4.0–12.0)	13.0 (9.0–16.0)	<0.01
Difficulty falling asleep, points, median (IQR)	1.0 (0–2.0)	1.0 (0–2.0)	1.5 (1.0–2.0)	<0.01
Difficulty staying asleep, points, median (IQR)	1.3 (0–2.0)	1.0 (0–2.0)	2.0 (1.0–2.0)	<0.01
Sleep diary (prospective parameters)				
Bedtime, clock time median (IQR)	23:11 (22:15–24:15)	22:55 (22:10–23:46)	23:22 (22:23–24:28)	0.02
Rising time, clock time median (IQR)	7:00 (6:19–7:47)	6:49 (6:11–7:42)	7:12 (6:21–7:48)	0.20
TST, min, median (IQR)	408.1 (354.8–473.6)	418.5 (391.3–484.2)	379.5 (333.4–457.5)	<0.01
SE, %, median (IQR)	91.0 (84.2–96.0)	93.0 (88.0–96.0)	90.5 (80.2–94.0)	<0.01
SOL, min, median (IQR)	21.4 (11.9–37.4)	18.4 (10.0–30.0)	23.2 (12.6–50.5)	0.04
WASO, min, median (IQR)	12.8 (3.2–33.3)	10.2 (2.7–25.5)	15.9 (3.5–38.3)	0.22
Objective sleep parameters (actigraphy)				
TST, min, median (IQR)	386.5 (331.6–436.6)	392.1 (349.8–461.1)	370.0 (315.4–430.7)	0.02
SE, %, median (IQR)	83.9 (78.3–87.6)	85.3 (79.7–89.2)	83.1 (76.6–86.9)	0.07
SOL, min, median (IQR)	15.9 (7.9–26.1)	12.3 (7.3–20.1)	16.8 (10.5–28.9)	0.01
WASO, min, median (IQR)	39.9 (26.7–56.9)	40.0 (28.9–57.9)	38.9 (25.3–55.6)	0.43

Data are expressed as median (interquartile range) or number (%). MADRS, Montgomery–Åsberg Depression Rating Scale; YMRS, Young Mania Rating Scale; ISI, Insomnia Severity Index; TST, total sleep time; SE, sleep efficiency; SOL, sleep onset latency; WASO, wake after sleep onset.

subjective and objective sleep parameters were evaluated using the Pearson correlation coefficient (*r*). Considering that SOL data in both sleep diary and actigraphy were not normally distributed, they were naturally log transformed for the analyses. The problem of multiple comparisons was addressed using Bonferroni corrections. The difference between subjective and objective sleep parameters were quantified using the 95% limits of agreement by the Bland–Altman plots, estimated by mean difference ± 1.96 standard deviation of differences. The difference between subjective and objective sleep parameters was adjusted for age (per year), gender (male or female), mood status (euthymic or residual symptomatic), insomnia (present or absent), and use of medications (antipsychotic, antidepressant, and hypnotic; yes or no) using an analysis of covariance. Furthermore, to estimate the correlation between mood symptoms (based on the MADRS and YMRS scores) and the difference between subjective and objective sleep parameters, we used Spearman's rank correlation coefficient (*rs*). All statistical data were analyzed using SPSS version 25.0 for Windows. A two-sided $p < 0.05$ was considered to have statistical significance.

3. Results

The median (IQR) age of the 164 eligible participants was 43.0 (33.0 to 51.0) years, and 88 patients (53.7%) were female (Table 1). Additionally, 163 (99.3%) participants had been prescribed with psychiatric medications, including lithium, anticonvulsants, antipsychotics, antidepressants, hypnotics, or anxiolytics. The median (IQR) values of the subjective and objective sleep parameters for all participants were as follows (Table 1): for ISI total score, 11.0 points (7.0 to 15.0 points; 115 participants [70%] had insomnia); sleep diary and actigraphy: TST, 408.1 (354.8 to 473.6) and 386.5 (331.6 to 436.6) min; SE, 91.0% (84.2% to 96.0%) and 83.9% (78.3% to 87.6%); SOL, 21.4 (11.9 to 37.4) and 15.9 (7.9 to 26.1) min; WASO, 12.8 (3.2 to 33.3) and 39.9 (26.7 to 56.9) min. In addition, the median (IQR) values of the MADRS and YMRS scores were 8.0 (3.2 to 13.7) and 2.0 (0 to 5.0) points, respectively. We then classified 98 (59%) participants as the residual symptomatic group and 66 (40%) as the euthymic group (Table 1). In the residual symptomatic group, 75 (45% of all patients) had depressive states (MADRS score ≥ 8 points; YMRS score < 8 points), 10 (6% of all patients) had manic states (MADRS score < 8 points; YMRS score ≥ 8 points), and 13 (8% of all patients) had mixed states (MADRS and YMRS score of ≥8 points). The residual symptomatic group had significantly higher ISI scores, delayed bedtime, shorter TST (according to both the sleep diary and actigraphy), lower SE (according to the sleep diary), and prolonged SOL (according to both the sleep diary and actigraphy) than did the euthymic group (Table 1). Except for MADRS and YMRS scores, the demographic and clinical characteristics of the euthymic and residual symptomatic groups did not differ significantly. Females showed significantly lower education level and employment status, lower use of lithium, higher ISI score (only difficulty falling asleep), and delayed bedtime and rising time than male (Supplemental Table 1).

For all participants, the TST assessed by sleep diary highly correlated with that by actigraphy; this correlation remained significant after correcting for multiple testing ($r = 0.81$, $p < 0.001$, Table 2). Meanwhile, the SOL assessed by sleep diary moderately correlated with that by actigraphy; this correlation also remained significant after correcting for multiple testing ($r = 0.47$, $p < 0.001$, Table 2). These correlations were observed in both the euthymic and residual symptomatic groups (TST: $r = 0.86$ and 0.77, respectively; SOL: $r = 0.51$ and 0.40, respectively;

Table 2
Pearson correlation coefficient between subjective and objective sleep parameters.

Subjective sleep parameters	Objective sleep parameters	All (n = 164)		Euthymic (n = 66)		Residual symptomatic (n = 98)	
		r	*p*	*r*	*p*	*r*	*p*
ISI (retrospective parameters)	**Actigraphy**						
Total score	TST	−0.04	0.61	0.14	0.24	−0.02	0.83
	SE	−0.15	0.05	0.00	0.96	−0.17	0.08
Difficulty falling asleep	SOL	0.22	0.004	0.21	0.08	0.16	0.11
Difficulty staying asleep	WASO	0.01	0.82	0.03	0.78	0.02	0.79
Sleep diary (prospective parameters)	**Actigraphy**						
TST	TST	0.81	<0.001	0.86	<0.001	0.77	<0.001
SE	SE	0.21	0.005	0.25	0.04	0.18	0.07
SOL	SOL	0.47	<0.001	0.51	<0.001	0.40	<0.001
WASO	WASO	0.17	0.02	0.26	0.03	0.14	0.16

ISI, Insomnia Severity Index; TST, total sleep time; SE, sleep efficiency; SOL, sleep onset latency; WASO, wake after sleep onset.

Table 2) and in both the insomnia and non-insomnia groups (TST: r = 0.80 and 0.86; SOL: r = 0.42 and 0.53, respectively; Supplemental Table 2). Conversely, the correlation between SE assessed by sleep diary and that by actigraphy was low, and no correlation was observed for WASO (Table 2). Moreover, the correlation between the ISI questionnaire and actigraphy sleep parameters was low or not observed at all (Table 2). Regarding the correlation between subjective and objective sleep parameters stratified by gender, the TST assessed by sleep diary highly correlated with that by actigraphy in both male and female (Supplemental Table 3). In addition, the SOL assessed by sleep diary moderately correlated with that by actigraphy in both male and female (Supplemental Table 3).

Fig. 1 shows the Bland–Altman plots of the difference (sleep diary parameters minus actigraphy parameters) against the mean (sleep diary parameters plus actigraphy parameter divided by 2) for the four sleep parameters (TST, SE, SOL, and WASO) in all participants. We found a higher variance in the difference along with the decrease in the mean value of SE and the increase in the mean value of SOL and WASO. In the sleep diary parameters, TST, SE, and SOL were overestimated by a mean of 28.1 min, 5.7%, and 9.5 min, respectively, and WASO was underestimated by 21.2 min in comparison with those in the actigraphy parameters. The median (IQR) values of the percentage difference (sleep diary parameters minus actigraphy parameters divided by actigraphy parameter) were as follows: TST, 6.2% (−0.2% to 13.6%); SE, 6.8% (0.7% to 13.8%); SOL, 44.1% (−21.1% to 143.6%); WASO, −66.5% (−94.2% to −12.6%). The mean (95% confidence interval) values of the

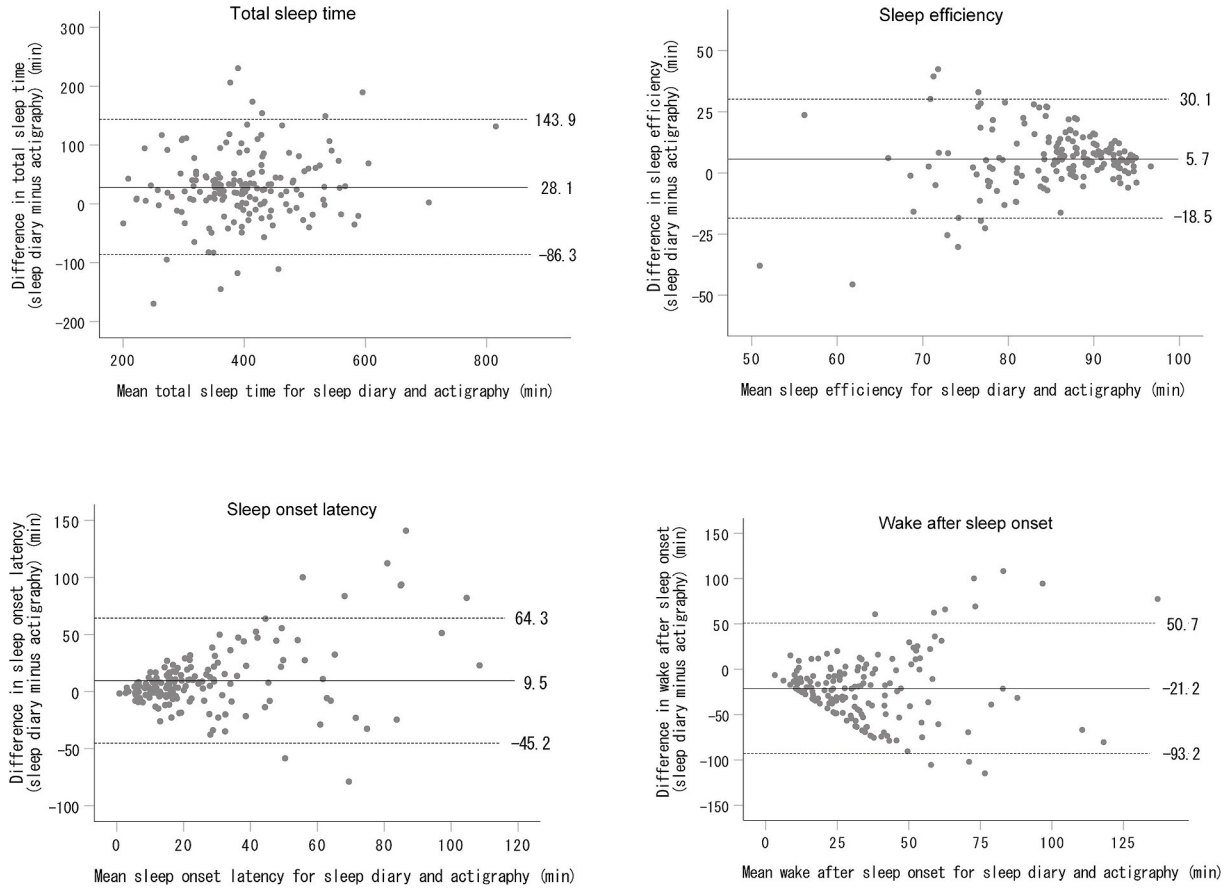

Fig. 1. Bland–Altman plot of subjective sleep assessed by sleep diary and objective sleep assessed by actigraphy in 164 patients with bipolar disorder. Solid lines represent mean difference, and dotted lines represent 95% limits of agreement (1.96 ± SD of difference).

difference (sleep diary parameters minus actigraphy parameters) adjusted for age, gender, mood status, insomnia, and use of medications were as follows: TST, 37.2 (26.7 to 47.7) min; SE, 7.5% (5.3% to 9.6%); SOL, 6.7 (1.6 to 11.7) min; WASO, −26.5 (−33.0 to −20.0) min. The use of antipsychotic medications was significantly associated with the difference between subjective and objective sleep parameters, including TST, SE, and WASO (Supplemental Table 4). Mood symptoms were not correlated with the difference between subjective and objective sleep parameters (Supplemental Table 5).

4. Discussion

This study evaluated the correlation and difference between subjective sleep assessed by the ISI questionnaire and sleep diary, and objective sleep measured by actigraphy. TST assessed by sleep diary strongly correlated with that by actigraphy. SOL assessed by sleep diary moderately correlated with that by actigraphy. These correlations remained significant regardless of being in the euthymic or residual symptomatic state and regardless of the presence or absence of insomnia. Furthermore, TST assessed by sleep diary was slightly different (6.2%) from that by actigraphy, whereas the correlations between WASO and SE assessed by sleep diary and by actigraphy were no and low, respectively.

Our results are consistent with those of previous studies that reported a correlation between subjective and objective sleep parameters. A previous study involving 26 patients with bipolar disorder remission reported that sleep duration and SOL assessed by the Pittsburgh Sleep Quality Index (PSQI) highly and moderately correlated with those by actigraphy, respectively ($rs = -0.76$ and 0.50) (Boudebesse et al., 2014). Similarly, another study investigating 133 individuals with bipolar disorder remission reported a moderate correlation between the subjective and objective measures of TST ($r = 0.53$) (Ihler et al., 2020). Additionally, in 39 symptomatic patients with bipolar disorder, objective TST assessed by actigraphy significantly correlated with subjective TST assessed by sleep diary ($r = 0.51$) (Gonzalez et al., 2013). In 27 euthymic patients with bipolar disorder, TST assessed by polysomnography highly correlated with that by sleep diary ($r = 0.71$) (Kaplan et al., 2012). Therefore, our study supports the results of previous studies. Moreover, high and moderate correlations between sleep diary and actigraphy were during the assessments of TST and SOL, respectively, irrespective of whether the patients were in the euthymic or residual symptomatic state and whether the patients had or did not have insomnia.

However, two previous studies reported no significant correlation between subjective and objective sleep in patients with bipolar disorder. Objective TST assessed by actigraphy did not significantly correlate with subjective TST assessed by PSQI in 24 symptomatic patients with bipolar disorder, but a correlation existed in the healthy control group (Krishnamurthy et al., 2018). Likewise, objective sleep duration assessed by actigraphy did not significantly correlate with subjective sleep duration assessed by PSQI in 31 patients with bipolar disorder (Kaufmann et al., 2019). Thus, the results were inconsistent between these previous studies and the present study. One possible explanation is the differences in the retrospective and prospective measurement of sleep. Two previous studies retrospectively assessed subjective sleep using the PSQI (Kaufmann et al., 2019; Krishnamurthy et al., 2018). In the present study, subjective sleep was assessed both retrospectively using ISI and prospectively using sleep diary. We found a high correlation between TST assessed by sleep diary and that by actigraphy and a low or no correlation between ISI and actigraphy parameters. Therefore, retrospective sleep assessment using PSQI and ISI questionnaire may cause recall bias in patients with bipolar disorder. Another possible explanation is the differences in the severity of mood symptoms. Although the mean scores on Hamilton Depression Rating Scale and YMRS in a previous study were 22.8 and 13.6 points, respectively (Krishnamurthy et al., 2018), the median scores of MADRS and YMRS in the residual symptomatic group of our study were 12.0 and 3.0 points, respectively. The severity of depressive symptoms has been reported to correlate with the discrepancy between the subjective and objective measures of TST (Gonzalez et al., 2013; Krishnamurthy et al., 2018). Therefore, the differences in mood symptom severity may lead to inconsistent results.

Moreover, a great discrepancy exists between subjective and objective sleep estimates in patients with bipolar disorder who tend to overestimate SOL and underestimate TST (Harvey et al., 2005; Ritter et al., 2016). In our study, SOL and TST assessed by sleep diary were both overestimates compared with those assessed by actigraphy (Fig. 1). The overestimate of subjective TST assessed by sleep diary may be possibly caused by the calculating methods of TST. Although we calculated the subjective TST as the time between bedtime and rising time (when the participant finally got out of bed), excluding the SOL and WASO, we did not exclude the time from wake-up time (when the participant woke up before getting out of bed) to rising time; hence, subjective TST may be overestimated. Another possible reason is that WASO assessed by sleep diary was underestimated compared with WASO assessed by actigraphy. Moreover, use of psychiatric medications may have led to overestimates of subjective TST. We found that the use of antipsychotic medications was significantly associated with the discrepancy between subjective and objective sleep parameters, including overestimates of TST and SE and underestimates of WASO. However, given that the median percentage difference between TST assessed by sleep diary and that by actigraphy was relatively small (6.3%), the use of the sleep diary in assessing the TST may be acceptable. Meanwhile, the median percentage differences were large between SOL and WASO separately assessed by sleep diary and by actigraphy (44.1% and 66.5%, respectively). Therefore, in patients with bipolar disorder reporting their sleep state using a sleep diary, clinicians should consider the possibility of SOL overestimation and WASO underestimation.

We also found that there were little sex differences in subjective and objective sleep parameters in patients with bipolar disorder. A previous study in 956 healthy elderly individuals reported sex differences in subjective and objective sleep parameters (van den Berg et al., 2009). If assessed by diary or interview, elderly women consistently reported shorter and poorer sleep than elderly men. In contrast, actigraphy sleep parameters showed poorer sleep in men. Unexpectedly, our results showed little gender differences in subjective and objective sleep parameters. Further investigation about gender differences subjective and objective sleep in bipolar disorder is necessary.

The findings of the present suggest that the TST measured via a sleep diary may be an alternative method for evaluating sleep in patients with bipolar disorder. Although objective tools such as polysomnography and actigraphy are indeed more accurate in assessing sleep than the sleep diary and questionnaire, only few facilities offer such objective tools. Sleep problems occur in 70% even patients with bipolar disorder remission (Harvey et al., 2005) and are associated with residual mood symptom, mood episode recurrence, and suicide ideation (Cretu et al., 2016; Gershon et al., 2017; Stange et al., 2016). Therefore, when polysomnography or actigraphy is unavailable, sleep diary may be used instead to assess sleep in patients with bipolar disorder.

Among the strengths of the present study are the relatively large sample size and the inclusion of both euthymic and symptomatic periods. However, this study also has some limitations. First, the study participants were not randomly selected; thus, selection bias might have influenced the results. Second, objective sleep was evaluated by actigraphy. No consensus has been established that actigraphy can accurately represent sleep data in patients with bipolar disorder. However, a previous study reported that actigraphy sleep parameters are similar to those of polysomnography when measuring sleep in patients with bipolar disorder (Kaplan et al., 2012). Moreover, conducting polysomnography in a home setting is difficult. Therefore, sleep evaluation by actigraphy for patients with bipolar disorder may be justified. Third, we administered ISI at the start of experimental period to evaluate the severity of the participants' insomnia during the previous week; thus,

the data collected for ISI reflected a time period different from that of the sleep diary and actigraphy. Such a difference may have affected the results. Therefore, the ISI scores, sleep diaries, and results of actigraphy that reflect the same time period should be studied further. Fourth, as mentioned previously, when we calculated the subjective TST, we did not exclude the time between wake-up time and rising time. Because some patients with bipolar depression complain of awakening too early in the morning (Harvey, 2008), we expected to find some differences between actual wake-up time and rising time. Fifth, we excluded patients with acute manic, mixed, and depressive episodes because we prioritized patient safety; hence the mood symptoms in the residual symptomatic group of our study were only mild to moderately severe. It was difficult to recruit outpatients with severe mood symptoms because patients with such symptoms are usually hospitalized until their condition improves. Therefore, patients with severe mood symptoms, including inpatients, must be evaluated to clarify the effect of mood state on the discrepancy between subjective and objective sleep parameters. Sixth, among the 218 outpatients participated in our study, 54 (24%) were excluded because of their inability to wear actigraphy or failure to complete the sleep diary. Therefore, our findings present only the results of the participants who completed both actigraphy and sleep diary at home. Finally, we did not form a control group, thereby preventing us to conclude whether our results were specific to bipolar disorder or not.

In conclusion, subjective TST assessed by sleep diary showed a high correlation with and a slight difference from objective TST assessed by actigraphy. Thus, TST assessment using a sleep diary may be useful in clinical practice when actigraphy or polysomnography is not easily available. However, further validation studies with larger and independent samples are needed.

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Author's contributions

Akari Fujita contributed to interpretation of results and preparation of the manuscript. Yuichi Esaki contributed to study design, data collection, data analysis, interpretation of results, and preparation of the manuscript. Kenji Obayashi contributed to study design, data analysis, interpretation of results, and preparation of the manuscript. Keigo Saeki contributed to preparation of the manuscript. Kiyoshi Fujita contributed to data collection and preparation of the manuscript. Nakao Iwata contributed to preparation of the manuscript. Tsuyoshi Kitajima contributed to study design, interpretation of results, and preparation of the manuscript.

Declaration of interest

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Appendix A. Supplementary data

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