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SCIENTIFIC INVESTIGATIONS

Actigraphy prior to Multiple Sleep Latency Test: nighttime total sleep time predicts sleep-onset latency

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Study Objectives: To evaluate the clinical utility of actigraphy as compared with sleep questionnaires prior to the Multiple Sleep Latency Test (MSLT) in a sleep disorders clinic population.

Methods: Twenty-eight clinically referred participants (mean age: 42.3 ± 18.8 years) completed the study protocol. On day 1, participants completed the following questionnaires: Epworth Sleepiness Scale (ESS), Insomnia Severity Index, Pittsburgh Sleep Quality Index (PSQI), Visual Analog Scale (affect, vigor), Patient Health Questionnaire, and Multidimensional Fatigue Symptom Inventory–Short Form. On days 1–8, participants wore an actigraph and completed a sleep diary to assess mean nighttime and mean daytime total sleep time and sleep efficiency or sleep percentage. On day 9, participants repeated the ESS and completed an MSLT. Correlations assessed mean MSLT sleep-onset latency (MSLT-SOL) vs actigraphy, sleep diary, and questionnaires. Chi-square analyses assessed abnormal MSLT-SOL (≤ 8 minutes) or daytime sleepiness (ESS ≥ 10) and referral question (ie, sleep-disordered breathing vs hypersomnolence disorder).

Results: Mean MSLT-SOL was correlated with nighttime total sleep time assessed via both actigraphy and diary, but not with questionnaires. Significant correlations emerged for ESS score on day 1 vs 9, actigraphy vs sleep diary mean nighttime total sleep time, and PSQI vs mean sleep diary sleep efficiency. There was no significant relationship between mean MSLT-SOL and referral question.

Conclusions: Our finding that total sleep time measured by actigraphy was associated with MSLT-SOL suggests it is useful in informing the interpretation of MSLT findings; however, it does not appear to be a viable substitute for MSLT for the measurement of objective sleepiness in clinical settings.

Keywords: hypersomnolence, actigraphy, Multiple Sleep Latency Test, Epworth Sleepiness Scale

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BRIEF SUMMARY

Current Knowledge/Study Rationale: Current hypersomnia assessment methods present several challenges such as poor correlation between self-report questionnaires and functioning, and dubious construct validity for laboratory protocols with high patient burden, cost, and lack of concurrence with daily sleep/wake patterns. This preliminary study examined the potential utility of actigraphy in the clinical evaluation of hypersomnia.

Study Impact: Daytime symptom questionnaires do not provide sufficient information with regard to subsequent Multiple Sleep Latency Test performance. Actigraphy is well established as a tool for quantification of night total sleep time, but despite devices being worn for 24 hours, it is not well studied for evaluation of daytime sleepiness. While actigraphy may be an option to document adequate sleep prior to Multiple Sleep Latency Test, there are few validated data in clinical populations.

INTRODUCTION

Daytime sleepiness is a common symptom in sleep disorder clinic populations[1]; however, the best method to evaluate sleepiness symptoms remains unclear. The most commonly used clinical tools to assess daytime sleepiness are patient-completed questionnaires such as the Epworth Sleepiness Scale (ESS).[2] However, questionnaires correlate poorly with objective measures of functioning, performance, and alertness,[3–5] and may therefore have low construct validity.[6]

When the diagnosis of a central disorder of hypersomnia is being considered, a laboratory Multiple Sleep Latency Test (MSLT) is conducted.[7] In contrast to questionnaires, laboratory MSLT combines objectivity with high construct validity, and the MSLT is considered the "gold standard" for objective evaluation of daytime sleepiness and the gold-standard clinical tool for the diagnosis of disorders of hypersomnolence.[8,9] Yet, as is true with many "gold standard" assessments, the MSLT is limited by high patient burden and cost. Furthermore, the MSLT assesses sleepiness in the laboratory environment, which may not reflect the true degree of impairment associated with the patient's habitual sleepiness, it is heavily influenced by the patient's recent sleep history, and the test-retest variability has not been well documented, with the possible exception of type I narcolepsy.[10,11]

The impact of insufficient sleep prior to the MSLT has led to requirements for documenting adequate sleep prior to

conducting the test,[9] as insufficient sleep in the nights prior to the test can lead to short sleep-onset latency (SOL) during the MSLT nap opportunities.[12] Insufficient sleep prior to testing therefore can make interpretation of abnormal MSLT findings difficult; however, there is lack of agreement about how best to capture sleep duration prior to testing. Recent clinical practice guidelines[13] and the *International Classification of Sleep Disorders*, third edition,[8] both suggest that wrist actigraphy may be useful, but is not required, in quantifying sleep time prior to the MSLT as this may provide a more precise estimate of true sleep time as compared with retrospective patient self-report or daily sleep diaries. Furthermore, the clinical standard of conducting an overnight polysomnography (PSG) recording the night prior to the MSLT may, in fact, inadvertently alter sleep or provide a false representation of the patient's habitual sleep.[14] In-laboratory PSG may lead to less sleep than the patient might normally get due to sleep disruption associated with the laboratory environment and PSG sensors. Alternatively, 1 night of adequate sleep during the PSG night might not be sufficient to make up for multiple nights of insufficient sleep leading up to the in-laboratory study.[15]

Studies using retrospective medical record review show that actigraphy may provide useful information over and above patient reported total sleep time (TST) prior to an in-laboratory MSLT.[16,17] For example, in a study of patients seen at a military hospital for evaluation of hypersomnia, TST was monitored with actigraphy and sleep diaries for 2 weeks prior to MSLT.[17] The authors found that actigraphy-measured average nightly sleep duration was shorter than retrospective self-reported TST or sleep-log recorded TST, and only actigraphy-measured TST for the 2 weeks prior to the MSLT was related to mean SOL during the MSLT. Furthermore, those with mean SOL≤ 8 minutes on the MSLT had significantly shorter sleep and lower sleep efficiency (SE) based on actigraphy, but not based on other measures. This study suggests that actigraphy provides additional useful information above and beyond sleep diaries in a retrospective chart review study. One important limitation is that the study included primarily males (87%) who were relatively young (mean age of 30 years), which does not reflect the full range of patients seen in nonmilitary sleep disorders centers.

In addition to the potential utility of actigraphy to quantify nightly sleep time prior to the MSLT, actigraphy also provides a glimpse into the patient's daytime sleeping, since devices are worn continuously and not only at night.[18] It is not clear, however, whether daytime sleep as estimated via actigraphy more closely corresponds to patient-reported sleepiness or to objective MSLT-assessed sleep tendency. This uncertainty limits the usefulness of daytime estimation of sleep time for clinicians.

This pilot study sought to investigate the potential utility of actigraphy in quantifying nighttime and daytime sleep during the week prior to the MSLT in a broad cross-section of patients referred to an academic sleep center. We aimed to explore the relationships between SOL on the MSLT (MSLT-SOL) and actigraphy-estimated sleep, sleep diary variables, and sleep-related questionnaires the week prior to the MSLT. Our goal was to understand whether actigraphy prior to the MSLT may be clinically informative. We hypothesized that nighttime TST assessed via actigraphy in the week prior to the MSLT would be a stronger predictor of mean MSLT-SOL than sleep diary variables or sleep-related questionnaires. We also hypothesized that daytime sleep time captured by actigraphy would be associated with patient-reported sleepiness and MSLT-SOL. Specifically, we expected that daytime sleep (ie, total daytime minutes and % time asleep) would (1) predict mean MSLT-SOL and (2) explain a significant proportion of the variance in mean MSLT-SOL, even after accounting for sleepiness reported on patient questionnaires (ie, Epworth Sleepiness Scale [ESS] score). We also conducted exploratory analyses to determine whether there was a relationship worth further exploration in future research between abnormal vs normal mean MSLT-SOL and either (1) high vs low self-reported daytime sleepiness or (2) referral for suspected sleep-disordered breathing (SDB) vs hypersomnolence disorders.

METHODS

Study procedures were reviewed and approved by the University of California, Los Angeles (UCLA), Institutional Review Board. Potential participants were recruited from the UCLA sleep disorders center during one of their clinical visits. All study procedures, including interviews, PSG, and MSLT recordings, were carried out at the UCLA Clinical Translational Research Center (CTRC) by CTRC staff and study personnel. Participants with a recent overnight clinical PSG recording for clinical purposes did not repeat the research PSG in the CTRC laboratory. Instead, variables were abstracted from the clinical reports.

Participants

In total, 29 sleep disorders clinic patients enrolled in the study. One participant did not complete the MSLT and was excluded from the analytic sample. During a clinical visit, patients were provided with information about the study and were invited to complete a brief screening assessment (described below). Using medical record documentation of the reason for referral to the sleep center, participants were categorized as either (1) referred for evaluation of SDB or (2) referred for specific evaluation of hypersomnolence disorders (eg, narcolepsy, idiopathic hypersomnia).

To enhance generalizability, we minimized exclusionary criteria to the extent possible. Only adult patients (age > 18 years) referred to and evaluated by a sleep specialist within the sleep disorders center were considered eligible to participate. Considerations in developing inclusion/exclusion criteria included factors likely to threaten the validity of self-report measures or wrist actigraphy, contribute to electroencephalographic abnormalities, or limit an individual's ability to complete study procedures. Potential participants were excluded for the following reasons: (1) movement disorders or limited mobility (eg, spinal cord injury or stroke that limits limb movements and threatens validation of actigraphy recording); (2) suspected or confirmed parasomnias (eg, REM [Rapid Eye Movement] Behavior Disorder); (3) seizure, neurocognitive, or severe psychiatric disorders

(eg, schizophrenia, dementia, severe depression, alcohol or drug use disorders with < 90 days' sobriety); (4) inability to spend 1 night and day in the sleep laboratory (eg, due to caregiving responsibilities); (5) use of sedating or stimulating psychoactive medications (eg, sedative hypnotics, anxiolytics, antidepressants); or (6) being too ill or frail to complete study activities. Individuals taking medications routinely for stable medical conditions (eg, lipid-lowering medications) were not excluded. Participants tracked nonexclusionary medication use during the week of actigraphy recording daily within the sleep dairy (described below in the "Study measures" section) to confirm that excluded medications were not used during the study.

Procedures

Interested individuals were screened by study staff during their in-person visit to the sleep disorders clinic or over the telephone shortly after their clinical visit. Study procedures were reviewed. Individuals who met basic eligibility criteria attended a face-to-face consent appointment at the UCLA CTRC (day 1). The study was explained in detail and written informed consent was obtained. Those who met all screening criteria completed a series of questionnaires about sleep and select comorbid conditions. Participants were provided with a sleep diary (based on the Consensus Sleep Diary[19]) to be completed every morning about the previous night's sleep and with a wrist actigraph, which they wore 24 hours a day at home for 1 week (night 1–day 8). Wrist actigraphs were worn and sleep diaries were maintained daily throughout the 1-week at-home monitoring period. At the end of the 1-week at-home monitoring, they returned to the CTRC sleep laboratory for an attended overnight PSG (night 8) followed by a daytime 5-nap research MSLT (day 9), following standard protocols and procedures. Questionnaire measures related to daytime sleepiness were completed twice, once on the first day of wrist actigraphy (day 1) and once on the day of the MSLT (day 9). (See **Table 1** for study measures by day and the "Study measures" section below for detailed descriptions of all questionnaires and instruments.)

Study measures

Participants completed several self-report measures assessing information on demographics and comorbidities to help characterize the sample. The self-reported Comorbidity Index,[20,21] a validated, 34-item self-report measure of physical (28 items) and mental (6 items) comorbidity, provided a comorbidity index score and individual comorbid conditions as key variables of interest. Questions on the Comorbidity Index reflect whether an individual has ever experienced a list of common physical or mental health conditions in their lifetime. Physical Component and Mental Component scores of the 12-item Short-Form Health Survey (SF-12)[22] were our main measures of health-related quality of life. The Patient Health Questionnaire–9 item (PHQ-9)[23] measured depressive symptom severity given the potential role of depression in daytime sleepiness and fatigue.

Daytime sleepiness and related symptoms were assessed via retrospective and prospective questionnaires. The main measure of patient-reported daytime sleepiness was the ESS[2] based on its

Table 1—Study measures by day of study.

Category and Measure	Day of Study								
	1	2	3	4	5	6	7	8	9
Questionnaires									
ESS	X								X
ISI	X								
PSQI									X
VAS	X								X
MFSI-sf	X								
Comorbidity Index	X								
SF-12	X								
PHQ-9	X								
Daily sleep measures									
24/7 Actigraphy	X	X	X	X	X	X	X	X	X
Daily sleep diary	X	X	X	X	X	X	X	X	X
Objective sleep measure									
PSG (overnight)								X*	
Hypersomnia diagnostic measure									
MSLT (daytime)									X

*Research PSG was not repeated if the patient had recently completed a clinical PSG. ESS = Epworth Sleepiness Scale, ISI = Insomnia Severity Index, MFSI-sf = Multidimensional Fatigue Symptom Inventory–Short Form, MSLT = Multiple Sleep Latency Test, PHQ-9 = Patient Health Questionnaire–9 Item, PSG = polysomnography, PSQI = Pittsburgh Sleep Quality Index, SF-12 = 12-item Short-Form Health Survey, VAS = Visual Analog Scale.

routine use in clinical care and for monitoring responsiveness to treatment of sleep disorders.[24] We included the Visual Analog Scale (VAS) for vigor and affect, which also has been shown to detect changes in sleepiness across patient groups and experimental settings.[25] We also used the Multidimensional Fatigue Symptom Inventory–Short Form (MFSI-sf)[26] as a measure of fatigue.

Participants wore an Actiwatch (Philips Respironics, Murrysville, PA) actigraph device on the nondominant wrist for 8 consecutive days and nights immediately prior to and including the day of the MSLT to assess for sleep and wake patterns prior to the MSLT. Medium threshold settings were used, and data were collected in 1-minute epochs. The automatic scoring algorithm in the device was used to determine sleep vs wake. Actigraphy data were scored according to standard visual review of raw data to eliminate technical (device failure) and situational (eg, device removed) artifact, followed by defining "nighttime" as the period from diary-reported bedtime to diary-reported rising time and "daytime" as the period from diary-reported rising time to diary-reported bedtime (sleep diary described below). The key actigraphy variables for the current study were the total daytime minutes of sleep (mean daytime TST), total nighttime minutes of sleep (mean nighttime TST), nighttime SE (mean nighttime sleep %), and the percentage of time asleep between morning rise time and bed time (mean daytime sleep %) averaged across the 1-week at-home monitoring period.

We compared hypersomnia as assessed with actigraphy with the "gold standard" American Academy of Sleep Medicine guidelines for the 5-nap MSLT.[9] Patients underwent a clinically ordered PSG. If participants did not have a clinical PSG prior to participation in the study, the participants spent 1 night in the CTRC where a nighttime research PSG was completed at their usual sleep time (as determined with sleep questionnaires completed on day 1). Both clinical and research PSGs as well as the MSLT followed standard protocols and procedures as described in the American Academy of Sleep Medicine guidelines[9] and were scored following the most recent American Academy of Sleep Medicine scoring manual at the time of the study.[27,28] Research PSG and MSLT data were collected and scored via Polysmith software (Nihon Kohden Corporation, Tokyo, Japan). Research PSG records were scored by a technician and reviewed by coauthor M.R.Z. to identify reasons why an individual may not be appropriate for MSLT (eg, REM Behavior Disorder).[27,28] MSLT records were scored by M.R.Z. While all participants completed 1 night of PSG, only the apnea-hypopnea index (AHI) is reported due to the focus of the current paper centering on comparing actigraphy with other methods of assessing sleepiness, as well as variation in how PSGs were performed and documented across participants (ie, in clinical vs research labs).

The daily sleep diary served 2 purposes. First, documented bedtimes and rise times were used to facilitate scoring of actigraphy, and these times were used to demarcate the daytime period for assessment of hypersomnia. The full diary was also used as a measure of self-reported daytime sleeping (mean daytime TST) and nighttime sleeping (mean nighttime TST) as well as nighttime SE (mean nighttime SE) averaged across the 1-week at-home monitoring period. We used an expanded version of the Consensus Sleep Diary[19] to request documentation of total minutes intentionally napping and inadvertently dozing each day.

To facilitate characterization of our study sample and assist in development of future studies, participants were asked to complete the 7-item Insomnia Severity Index,[29] which is widely used to assess insomnia severity in clinical and research settings, and the 19-item Pittsburgh Sleep Quality Index (PSQI)[30] to quantify global patient-reported sleep quality over the past month. We also used the nighttime TST item from the PSQI.

Data analysis

The primary analyses addressed the study aims focused on patient-reported sleepiness, actigraphy, patient-reported measures of sleep including sleep diary and questionnaires, and the MSLT. After describing the sample using descriptive statistics, we examined whether there was a significant correlation between ESS total score at day 1 (baseline) and day 9 (day of MSLT), and between PHQ-9 (with the sleep item excluded from the total score) and our sleep outcomes of interest. We ran bivariate Pearson correlations between mean MSLT-SOL and each of the 4 actigraphy measures (nighttime and daytime TST, nighttime and daytime sleep %), 2 sleep diary measures (nighttime TST and SE), PSQI (nighttime TST and total score), the ESS total score (day 9), and AHI. To account for the potential implications of SDB symptoms on sleep and daytime sleepiness, we also assessed the same correlations separately by SDB status (AHI $<$ or $\geq$ 5 events/h). Finally, we conducted chi-square analyses to determine whether (1) high or low levels of self-reported sleepiness (ESS score $<$ 10 or $\geq$ 10, respectively) or (2) referral question (suspected SDB or hypersomnolence disorder) were associated with abnormal mean MSLT-SOL ($\leq$ 8 minutes) and whether PSG on the night prior to MSLT (yes or no) was associated with abnormal mean MSLT-SOL or excessive self-reported sleepiness. A total of 9 (31.0%) participants completed a PSG the night prior to the MSLT, 4 of whom had an abnormal MSLT-SOL ($\geq$ 8 minutes) and 6 of whom had an abnormal ESS (day 9; $\geq$ 10). There were no significant associations between PSG on the night prior to MSLT (yes/no) and abnormal mean MSLT-SOL or self-reported sleepiness (day 9 ESS score $<$ 10 or $\geq$ 10) on the day of the MSLT. As a result, we present the findings for the combined group. As this was a pilot study, we computed the required sample size using a framework recommended for pilot studies and used α = .20 as the threshold for statistical significance as recommended by Stallard[31] since the intention of this study was to explore variables important for future study. All statistical analyses were conducted using Stata/MP version 15.1 (StataCorp, 2019; StataCorp LLC, College Station, TX).

RESULTS

A total of 28 individuals comprised the analytic sample for the study (**Table 2**). Sleep measures are detailed in **Table 3**. One participant did not provide responses to 2 questions on the PSQI and a total score could not be calculated as a result. All other measures from the participant with the missing global PSQI are included in the results. The mean number of comorbidities on the Comorbidity Index was 4.0 (SD = 3.8; range = 1–16 conditions).

Table 2—Participant characteristics.

Characteristics	n	Mean ± SD or n (%)	Range
Demographics			
Age in years, mean ± SD	28	42.3 ± 18.8	19–77
Race/ethnicity, n (%)	28		
Non-Hispanic White		19 (67.9)	—
Asian		6 (21.4)	—
Hispanic or Latino/a		2 (7.1)	—
Black or African American		2 (7.1)	—
American Indian or Alaskan Native		1 (3.6)	—
Other race		1 (3.6)	—
Sex, n (%)	28		
Male		14 (50.0)	—
Female		14 (50.0)	—
Years of education, mean ± SD	28	16.6 ± 2.4	13–22
Health and comorbidities			
Comorbidity Index, total score (0–36)	28	4.0 (3.8)	0–16
BMI, mean ± SD, kg/m^2	28	27.2 ± 6.0	18–40
PHQ-9	28	7.5 ± 5.9	0–20
PHQ-9 (sleep item excluded)	28	5.8 ± 5.0	0–17
SF-12 Health Survey, Mental Component	28	46.5 ± 12.4	16.7–66.5
SF-12 Health Survey, Physical Component	28	43.9 ± 13.3	12.0–59.4
Sleep, sleepiness, and alertness questionnaires			
ESS, mean ± SD (day 1)	28	11.1 ± 5.9	0–21
ESS, mean ± SD (day 9)	28	11.0 ± 5.9	2–24
ISI	28	11.7 ± 6.4	0–24
VAS Global Vigor Scale, mean ± SD	28	56.7 ± 23.5	9.8–94.3
VAS Global Affect Scale, mean ± SD	28	64.8 ± 9.3	42.8–78.3
MFSI-sf	28	34.6 ± 23.1	4–79
Polysomnography (PSG)			
AHI, mean ± SD	28	11.5 ± 18.1	0–67

AHI = apnea-hypopnea index, BMI = body mass index, ESS = Epworth Sleepiness Scale, ISI = Insomnia Severity Index, MFSI-sf = Multidimensional Fatigue Symptom Inventory–Short Form, PHQ-9 = Patient Health Questionnaire–9 Item, SD = standard deviation, SF-12 = 12-item Short-Form Health Survey, VAS = Visual Analog Scale.

The most commonly reported conditions were anxiety (42.9%), depression (39.3%), back pain (35.7%), and irregular heartbeat (32.1%). There were significant correlations between PHQ-9 with the sleep item excluded and actigraphy nighttime total sleep (r[28] = .52, P = .005) and actigraphy daytime total sleep (r[28] = .25, P = .202), but not with other sleep outcomes.

Half of the participants were referred for evaluation of possible SDB (n = 14, 50.0%), and the remainder were referred to assess for disorders of hypersomnolence such as narcolepsy or idiopathic hypersomnia (n = 14, 50.0%). We conducted a chi-square analysis to determine whether there was a relationship between referral reason and AHI and found a significant association (X^2[1] = 5.14, P = .023), such that 71% (n = 10) of individuals referred for SDB had an AHI ≥ 5 events/h and 71% (n = 10) of individuals referred for evaluation of disorders of hypersomnolence had an AHI < 5 events/h.

Mean MSLT-SOL vs actigraphy, sleep diary, daytime sleepiness, and AHI

Table 4 shows correlation coefficients between mean MSLT-SOL and sleep measures. Significant correlations were observed

Table 3—Sleep measures for study participants.

	Screen (Day 1)	Home Monitoring (Days 2–8)		Day of MSLT (Day 9)		
Sleep Variables	**ESS (n = 28)**	**Diary (n = 28)**	**Actigraphy (n = 28)**	**PSQI (n = 27)**	**ESS (n = 28)**	**MSLT (n = 28)**
Nighttime TST, min	—	432.2 ± 78.5	438.8 ± 57.9	439.2 ± 109.7	—	—
Nighttime sleep efficiency or percentage,* %	—	85.3 ± 8.9	84.1 ± 6.3	83.6 ± 13.6	—	—
Daytime TST, min	—	29.5 ± 29.3	151.4 ± 102.0	—	—	—
Daytime sleep, %	—	—	17.1 ± 11.5	—	—	—
MSLT-SOL, min	—	—	—	—	—	9.8 ± 4.6
Questionnaire total score	11.1 ± 5.9	—	—	9.0 ± 3.8	11.0 ± 5.9	—

Values are reported as mean ± standard deviation; n = 28. *Sleep diary is reported as sleep efficiency and actigraphy is reported as sleep percentage. As described in the Results, 1 participant did not complete the MSLT and thus is not included in any analyses, and another participant did not complete the PSQI. ESS = Epworth Sleepiness Scale, MSLT = Multiple Sleep Latency Test, MSLT-SOL = average MSLT sleep-onset latency, PSQI = Pittsburgh Sleep Quality Index (past-month time frame), TST = total sleep time.

between mean MSLT-SOL and mean nighttime TST assessed by both actigraphy ($P < .20$; **Figure 1A**) and sleep diary ($P < .05$; **Figure 1B**), but not between mean MSLT-SOL and nighttime TST as reported on the PSQI (**Figure 1C**). Mean MSLT-SOL was not significantly correlated with AHI, self-report measures of insomnia (Insomnia Severity Index), sleep quality (PSQI), daytime sleepiness (ESS day 1 or 9), mood (VAS affect), alertness (VAS vigor), or fatigue (MFSI-sf total score). No other significant correlations were observed between mean MSLT-SOL and actigraphy or sleep diary (ie, daytime TST, daytime or nighttime sleep efficiency/percent), or between mean MSLT-SOL and sleep-related symptom questionnaires.

Data were also evaluated by SDB status. In participants without SDB (AHI < 5 events/h), a significant correlation emerged between mean MSLT-SOL and mean actigraphy nighttime TST ($r[14] = .37$, $P = .198$), but not for other actigraphy or sleep diary indices including sleep diary nighttime TST ($r[14] = .36$, $P = .208$). In participants with SDB (AHI ≥ 5 events/h), a significant correlation emerged between mean MSLT-SOL and mean sleep diary nighttime TST ($r[14] = .57$, $P = .032$), but not for other actigraphy or sleep diary indices.

Actigraphy, sleep diary, daytime sleepiness, sleep-related symptom questionnaires, and AHI

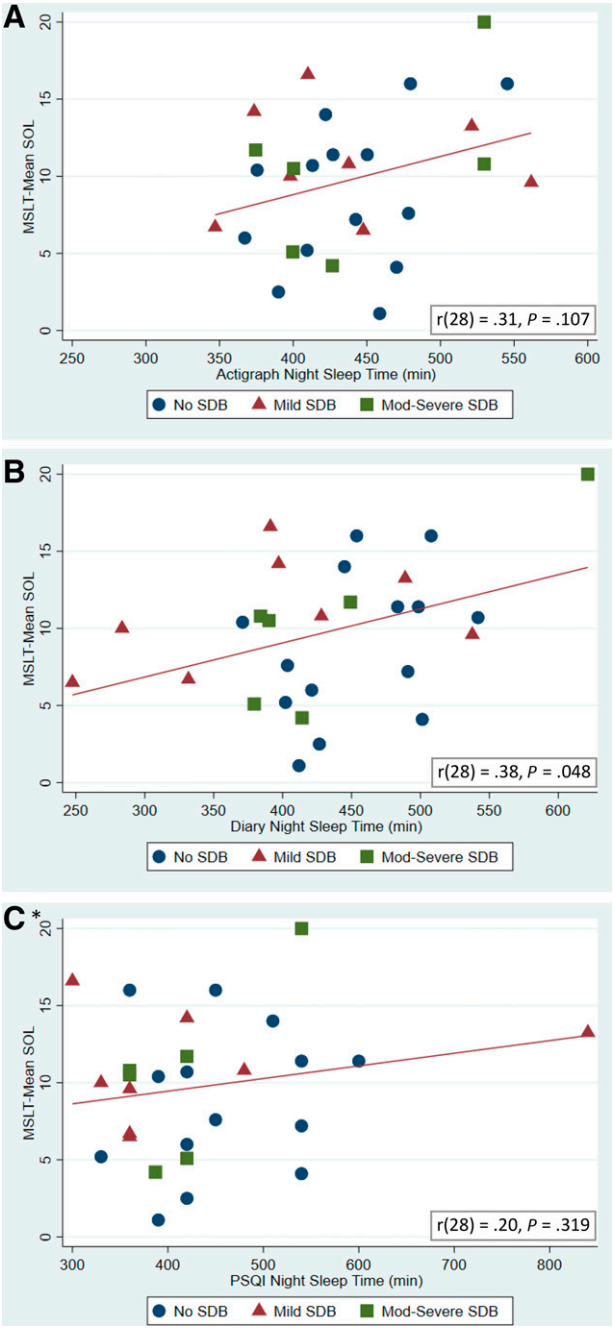
Significant correlations were observed between mean actigraphy nighttime TST and mean sleep diary nighttime TST ($r[28] = .49$, $P = .009$), ESS score between day 1 and day 9 ($r[28] = .75$, $P = .000$), mean nighttime sleep diary SE and PSQI ($r[27] = -.678$ $P = .0001$), mean actigraphy daytime TST and AHI

Table 4—Correlation coefficients (*r*) for mean MSLT-SOL and sleep measures.

Sleep Measure	*r*	*P*
Actigraphy		
Mean daytime TST, min	.22	.252
Mean daytime sleep, %	.22	.260
Mean nighttime TST, min	.31	.107
Mean nighttime sleep, %	.08	.679
Sleep diary		
Mean daytime TST, min	.13	.514
Mean nighttime TST, min	.38	.048
Questionnaires		
PSQI nighttime TST, min	.20	.319
ESS total score (day 1)	.18	.357
ESS total score (day 9, same day as MSLT-SOL)	−.02	.938

n = 28. ESS = Epworth Sleepiness Scale, MSLT = Multiple Sleep Latency Test, PSQI = Pittsburgh Sleep Quality Index (past month), SOL = sleep-onset latency, TST = total sleep time.

Figure 1—Scatterplots of mean MSLT-SOL and TST via actigraphy, sleep diary, and PSQI.



Mean MSLT-SOL (*y*-axis) with **(A)** mean actigraphy nighttime TST, **(B)** mean sleep diary nighttime TST, and **(C)** PSQI nighttime TST (*x*-axes). Blue circles represent patients with no SDB (AHI < 5 events/h), red triangles represent patients with mild SDB (AHI 5–14 events/h), and green squares represent patients with moderate to severe SDB (AHI ≥ 15 events/h). *MSLT-SOL vs PSQI was not significant when excluding the potential outlier: $r(27) = .13$, $P = .521$. AHI = apnea-hypopnea index, MSLT = Multiple Sleep Latency Test, PSQI = Pittsburgh Sleep Quality Index, SDB = sleep-disordered breathing, SOL = sleep-onset latency, TST = total sleep time.

($r[28] = .42$, $P = .025$), and mean actigraphy daytime SE and AHI ($r[28] = .40$, $P = .037$). No other significant correlations were observed between daytime or nighttime actigraphy, daytime or nighttime sleep diary, sleep-related symptom questionnaires, or AHI.

Mean MSLT-SOL, daytime sleepiness, referral question, and SDB status

There were no significant associations between abnormal mean MSLT-SOL (< or ≥ 8 minutes) and low vs high levels of self-reported sleepiness (day 1 ESS score < 10 or ≥ 10, respectively) or referral question (suspected SDB vs hypersomnolence disorder). There were also no significant relationships between abnormal mean MSLT-SOL (< or ≥ 8 minutes) and SDB status (AHI < 5, 5–14, or ≥ 15 events/h).

DISCUSSION

In this pilot study, we sought to explore the utility of actigraphy in the week prior to MSLT in characterizing MSLT results, as well as to examine different methods of evaluating sleepiness in a clinical sample. It should be noted that an α level of .20 was utilized in order to identify variables of interest for further study, and therefore, the study results should be interpreted with caution. While prior work has focused only on patients referred for evaluation of hypersomnia disorders,[16,17] we sought to understand the broader utility of actigraphy in sleep medicine practice, including both patients referred for evaluation of hypersomnia and patients referred for other indications. In our study, approximately one-half were referred for evaluation of SDB and one-half were referred for evaluation related to hypersomnia.

We found that nighttime TST documented by sleep diary ($P < .05$) or actigraphy ($P < .20$) correlated with mean MSLT-SOL, but that questionnaire measures did not. When separated by SDB status, differences emerged for the correlations between mean MSLT-SOL and nighttime TST measures. Specifically, MSLT-SOL was correlated with actigraphy nighttime TST for participants without SDB (AHI < 5 events/h), whereas MSLT-SOL was correlated with sleep diary nighttime TST for participants with SDB (AHI ≥ 5 events/h). Interestingly, the mean nightly TST was, on average, approximately 7 hours when measured by sleep diary, actigraphy, or using the self-report item on the PSQI; however, PSQI-reported sleep duration was not related to MSLT-SOL, supporting the requirement for either sleep diary or actigraphy outlined in the *International Classification of Sleep Disorders*, third edition, for establishing a diagnosis of hypersomnia disorders.[8] This also suggests that simple screening tools used in clinical settings may not provide a sufficient picture of factors contributing to hypersomnia. In fact, the ESS, which is commonly used in clinical practice, was unrelated to MSLT-SOL or to any actigraphy or sleep diary variables. This lack of correlation between patient-reported and objectively measured daytime sleepiness has been previously

reported.[32,33] Of note, the strong correlation between repeated measurement of ESS provides evidence that the ESS is a stable measure of self-reported sleepiness.[32,33]

Another critical question we sought to address was whether daytime sleeping averaged across 1 week at home estimated by actigraphy could be a surrogate for abnormal sleepiness as measured by the MSLT-SOL. In fact, we did not find evidence for this hypothesis. Although actigraphy estimated more daytime sleep than sleep diaries (2.4 hours via actigraphy vs 0.5 hours via sleep diary), neither of these measures related to objective sleepiness. Actigraphy captures "likely sleep" and sleep diaries capture "perceived sleep," and these constructs are quite different—even people with high levels of sleepiness may be able to sustain wakefulness during their normal daily activities. Additionally, actigraphy may have overestimated daytime sleep. As actigraphy derives its measure of "likely sleep" from wrist movement (vs electroencephalography-based PSG data), sitting or lying still for an extended period of time while awake may be miscategorized as sleep by the automated scoring algorithm. It should be noted that the validity of actigraphy in the detection of daytime sleep is not well established and largely depends on the population being evaluated.[34,35] It is also possible that some individuals use planned daytime naps as a coping strategy for sleepiness, and therefore may not be likely to "doze" in the other situations queried on the ESS.

In addition to the main analyses, we examined several potential covariates. We found that there were no differences between patients referred for evaluation of SDB and those referred specifically for hypersomnia in abnormal scores on the MSLT-SOL or on the ESS. This suggests that clinical evaluation of sleepiness may be indicated not only in patients for whom that is their primary complaint but also for patients presenting with other clinical conditions. While the AHI was correlated with daytime TST and sleep percentage assessed via actigraphy, AHI was not correlated with self-reported (ESS) or objective (MSLT-SOL) sleepiness, nighttime actigraphy sleep percentage, or nighttime TST assessed by either actigraphy or sleep diary. Thus, SDB status emerged as a possibly relevant covariate in this sample with regard to sleep-wake assessment as measured by actigraphy. However, as stated above, there are caveats to the interpretation of daytime actigraphy regarding the possibility of overestimation of daytime sleep. A higher PHQ-9 was associated with greater nighttime and daytime total sleep assessed by actigraphy. It is possible that individuals with elevated symptoms of depression may experience hypersomnia or may spend more time in sedentary positions, resulting in exaggerated sleep time as estimated by wrist actigraphy; therefore, depressive symptomology and associated sleep and behavioral patterns may be relevant in the assessment of disorders of hypersomnolence.

The findings from this study suggest that actigraphy does not appear to be a viable replacement for mean MSLT-SOL in terms of estimating objective daytime sleepiness; however, actigraphy may be useful in estimating nighttime sleep time prior to an MSLT. Future studies will be needed to develop technologies and approaches to quantify sleepiness that are cost-effective and valid in clinical populations.

Methodological considerations

These data are presented with caveats regarding limitations of our findings. Due to the pilot nature of the study and our relatively small sample, any conclusions about these results should be considered tentative, pending further confirmation. We used a more generous *P* value of .20 as recommended for pilot studies,[31] lessening the risk of type II error (in other words, greater power to detect possible associations or reducing "false negatives") but increasing the risk of type I error (a "false positive").[36] As with any study, we would emphasize that a failure to reject the null hypothesis does not provide evidence for the null hypothesis, and the difference between *P* values alone in independently conducted correlations, such as for the correlations between mean MSLT-SOL and TST assessed by either sleep diary ($P < .05$) or actigraphy ($P < .20$), does not adequately convey which of these measures is a better predictor of MSLT-SOL. Given the greater risk of type I error in this study, the findings should be replicated before they are applied to clinical practice, ideally by using a noninferiority approach, which is powered to permit conclusions that associations among variables are smaller than a prespecified threshold.

In addition to statistical caveats, there are also limitations to the interpretation of the study results with regard to our study sample. Two-thirds of participants identified as "non-Hispanic White," making it difficult to consider race/ethnicity or cultural factors that may influence perceptions of sleep and sleepiness. To enhance recruitment, we did not require patients who had recently completed an in-laboratory study as part of their clinical evaluation to repeat the PSG on the night prior to the MSLT in order to reduce participant burden, and there is some debate about whether the sleep disruption during an in-laboratory PSG might lead to sleep duration that is actually shorter than the sleep the individual would have obtained in their home sleep environment the night before the test. However, in our sample, there was no association between PSG on the night prior to MSLT and abnormal MSLT-SOL or excessive self-reported sleepiness on the day of the MSLT. This suggests that actigraphy and sleep diary the week prior to the MSLT may be an alternative to conducting a PSG the night prior to the MSLT when a PSG has been performed previously. Of the individuals in the study who demonstrated an AHI ≥ 5 events/h, we do not have access to treatment adherence data.

Additionally, our sample endorsed a history of comorbid mood and anxiety disorders on a self-report comorbidity scale. As we did not conduct a clinician-administered diagnostic assessment and given the bidirectionality between sleep and psychiatric symptoms, it is difficult to disentangle the potential influence of psychiatric symptoms on sleep measures. Future studies should more thoroughly evaluate the effects of covariates that are associated with daytime sleepiness, such as comorbid sleep disorder and psychiatric symptoms, on diagnostic outcomes in the assessment of disorders of hypersomnolence.

Implications

Our preliminary findings support the use of either sleep diary or actigraphy to determine TST in the week leading up to an

MSLT, and do not support the use of actigraphy as a diagnostic tool for daytime sleepiness. Given the relationship between prior week nighttime sleep and MSLT-SOL, further investigations into extending sleep time as a potential intervention to reduce daytime sleepiness in clinical populations, including patients not referred specifically for evaluation of hypersomnia and SDB, are warranted and may be important prior to initiating pharmacological treatments for sleepiness.

ABBREVIATIONS

AHI, apnea-hypopnea index
CTRC, UCLA Clinical Translational Research Center
ESS, Epworth Sleepiness Scale
MFSI-sf, Multidimensional Fatigue Symptom Inventory-Short Form
MSLT, Multiple Sleep Latency Test
PHQ-9, Patient Health Questionnaire–9 item
PSG, polysomnography/polysomnogram
PSQI, Pittsburgh Sleep Quality Index
SDB, sleep-disordered breathing
SE, sleep efficiency
SOL, sleep-onset latency
TST, total sleep time
UCLA, University of California Los Angeles

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