

Monitoring Sleep in the Real World

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Sleep T32

January 10, 2020

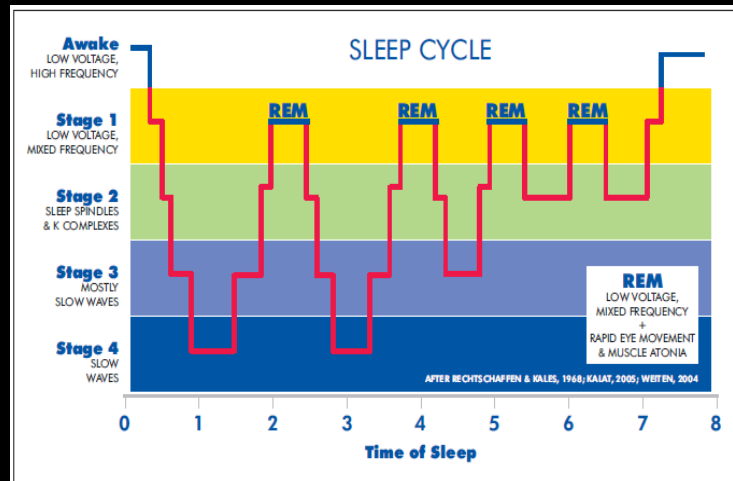
Overview

- ◇ Sleep monitoring: the “Gold Standard”
- ◇ “Real World” options
 - ◇ Actigraphy
 - ◇ Fitness Trackers
 - ◇ Apps
 - ◇ Passive Sensing
 - ◇ Deeper dive: Sleep Diaries

The Gold Standard: Polysomnography



Hypnogram



Polysomnographic recording



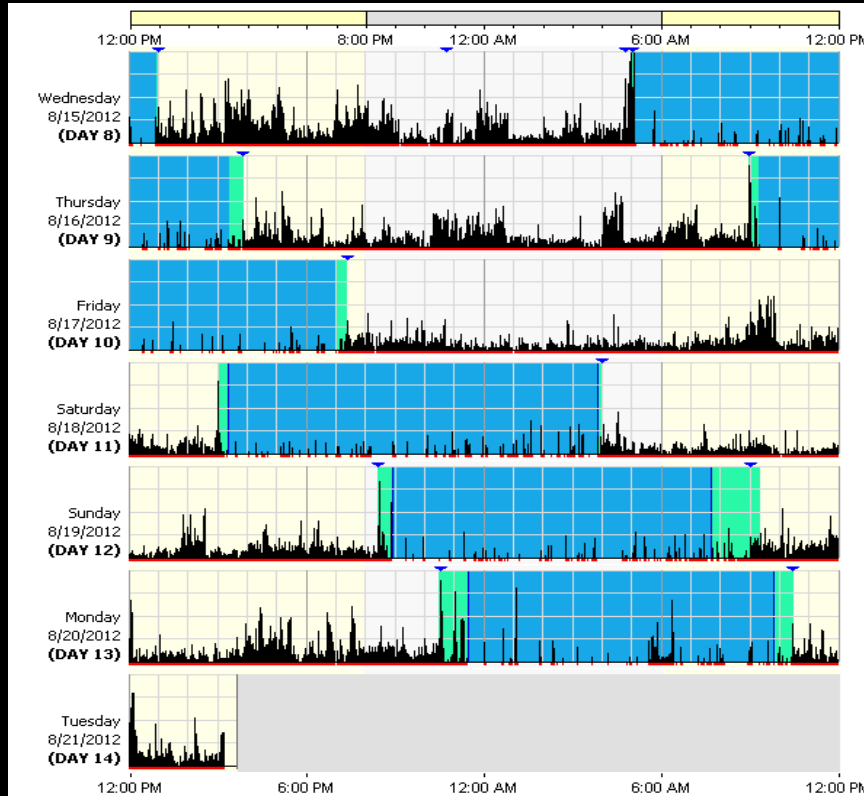
Advantages?
Disadvantages?

Options that (may) Work Better in the “Real World”

- ◇ Actigraphy
- ◇ Fitness Trackers, Wearables, Nearables
- ◇ Sleep Diary
- ◇ Apps
- ◇ Passive Sensing...

Actigraphy

Advantages?
Disadvantages?



- ◇ Review and meta-analysis of 96 studies, n=4134 participants

Compared to PSG:

- ◇ Among healthy adults, trend for ACT to overestimate TST and SE; underestimate WASO; significantly underestimated SOL
- ◇ Among adults with chronic conditions ACT overestimated TST and SE, underestimated ACT; trend to underestimate WASO

Fitness Trackers



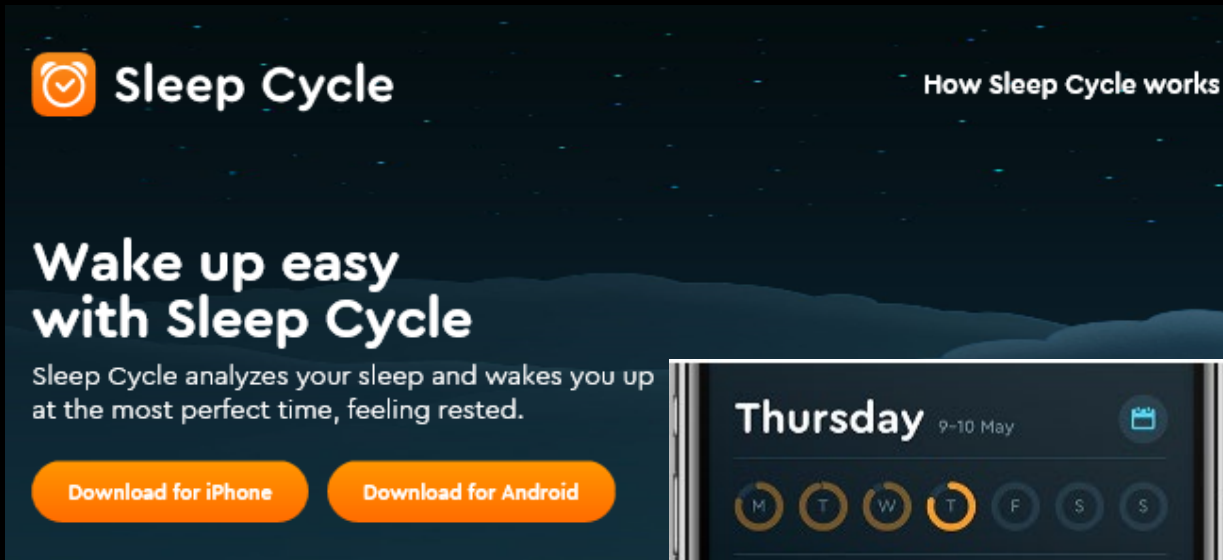
Advantages?
Disadvantages?

- ◇ Limited validity studies!
- ◇ Fitbit and Jawbone UP overestimated TST, SE, and SOL, underestimated WASO compared to PSG and/or actigraphy
- ◇ Fair to good at detecting sleep but poor at determining wakefulness

https://article.images.consumerreports.org/prod/content/dam/cro/news_articles/health/CR-BG-Fitness-Tracker-Hero-08-16

Mansukhani & Kolla, 2017, *Cleveland Clinic Journal of Medicine*

Apps



Sleep Cycle How Sleep Cycle works

Wake up easy with Sleep Cycle

Sleep Cycle analyzes your sleep and wakes you up at the most perfect time, feeling rested.

Download for iPhone Download for Android

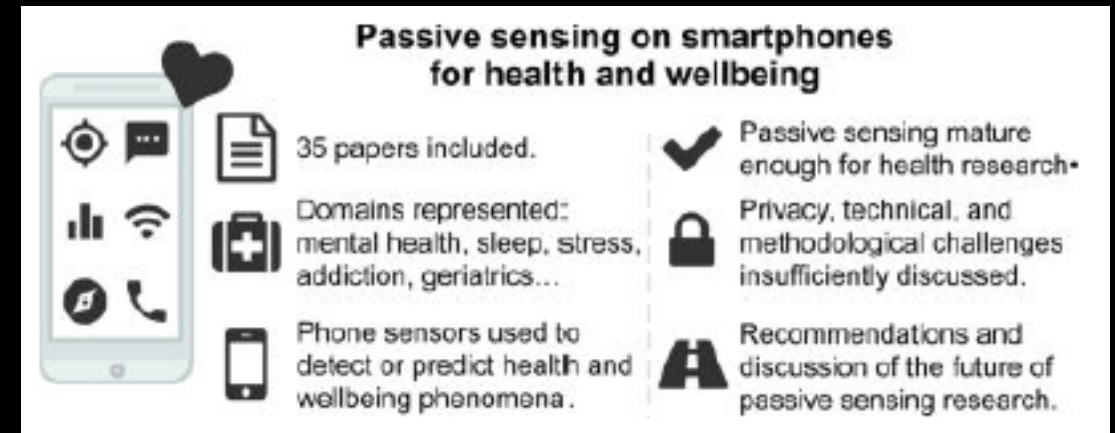
Advantages?
Disadvantages?



- ◇ Limited evaluation and validity studies
- ◇ Among healthy, apps meet or exceed accuracy of actigraphy in sleep-wake discrimination, most overestimate sleep
 - ◇ Accuracy drops as SE drops
- ◇ Most apps show poor correlation with PSG substages
- ◇ Fair to good at detecting sleep, but poor at determining wakefulness

Passive Sensing

- ◇ The capture of data about a person without extra effort on their part (using wearable, portable, or mobile computing)
 - ◇ Also called 'context-aware computing'
- ◇ Systematic review of smartphone-based PS
 - ◇ N=35 studies, n=6 on sleep
 - ◇ Only n=2 on Apple iOS (why??)

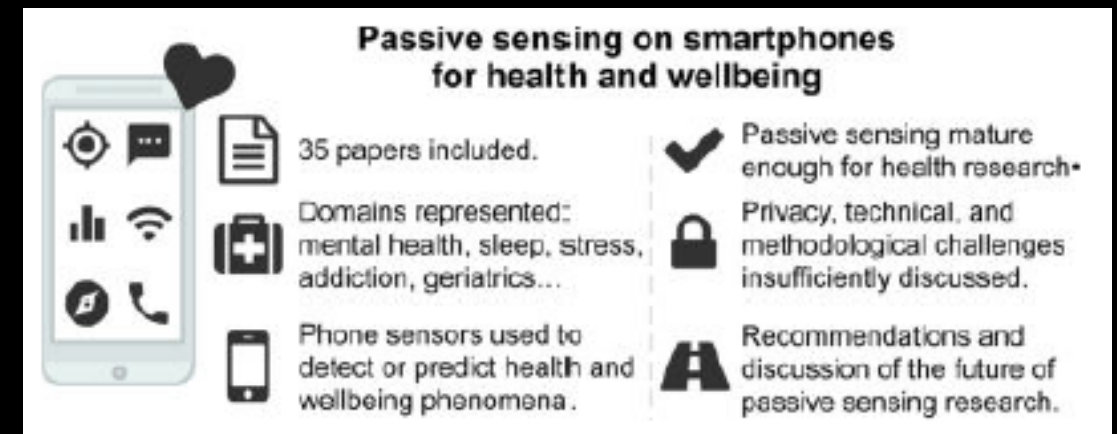


Passive Sensing

Author (Year) Location	Study Purpose	Principal Findings	Sensors Used	Sample Size & Type	Study Length (Days)
Bai et al. (2012) [33] China	Predict sleep quality from smartphone data collected during the day	Prediction of sleep quality with 78% accuracy, using a factor graph model.	<ul style="list-style-type: none"> • Accelerometer • Call logs • GPS • Light sensor • Microphone • SMS patterns 	15 Not specified	30
Natale et al. (2012) [51] Italy	Compare commercial sleep monitoring device data with three smartphone accelerometer algorithms for assessing sleep	<ul style="list-style-type: none"> • No statistical difference for total sleep time between the best performing algorithm and the commercial monitoring device. • Agreement rate on sleep-wake discrimination of 90% between the best performing algorithm and the commercial monitoring device. 	<ul style="list-style-type: none"> • Accelerometer 	13 General sample	4.8 [*]
Chen et al. (2013) [40] USA	Compare an application detecting sleep from smartphone data with three other sleep detection methods	<ul style="list-style-type: none"> • Better user experience and lower perceived intrusiveness for the passive sensing application than for the other sleep detection methods • Greatest error in the estimation of sleep duration (+/- 43 min) compared to the other sleep detection methods. 	<ul style="list-style-type: none"> • Accelerometer • Device activity • Light sensor • Microphone 	8 University students	7
Abdullah et al. (2014) [30] USA	Predict sleep time, duration, and deprivation from smartphone data	Social jetlag, sleep inertia, and sleep debt can be estimated from sensor data.	<ul style="list-style-type: none"> • Application usage • Browser history • Call logs • Device activity • SMS patterns 	9 University students	91.1 [*]
Min et al. (2014) [50] USA	Detect sleep and sleep quality in natural settings	<ul style="list-style-type: none"> • Detection of sleep with 94% accuracy using a Bayesian network with feature selection model for the individual model. • Detection of sleep quality with 84% accuracy using a Bayesian network/feature selection individual model, and 81% accuracy using a Bayesian network/feature selection global model. 	<ul style="list-style-type: none"> • Accelerometer • Application usage • Device activity • Light sensor • Microphone • Proximity sensor 	27 General sample	30
Bhat et al. (2015) [37] USA	Compare a commercial phone sleep monitoring application for iPhone with in-laboratory polysomnography	Detection of sleep by the application with 90% sensitivity and 50% specificity.	<ul style="list-style-type: none"> • Accelerometer 	20 General sample	6

Passive Sensing

- ◆ The capture of data about a person without extra effort on their part (using wearable, portable, or mobile computing)
 - ◆ Also called 'context-aware computing'
- ◆ Systematic review of smartphone-based PS
 - ◆ N=35 studies, n=6 on sleep
 - ◆ Only n=2 on Apple iOS (why??)
- ◆ Challenges: battery drainage, lack of sensor precision, difficulty accessing data, privacy issues



Advantages?
Disadvantages?

Sleep Diaries

- ◇ Gold standard for subjective sleep assessment (at least as of 2012)
- ◇ Subjective reporting can be important
- ◇ Recently standardized

Advantages?
Disadvantages?

THE CONSENSUS SLEEP DIARY

<http://dx.doi.org/10.5665/sleep.1642>

The Consensus Sleep Diary: Standardizing Prospective Sleep Self-Monitoring

Colleen E. Carney, PhD¹; Daniel J. Buysse, MD²; Sonia Ancoli-Israel, PhD³; Jack D. Edinger, PhD⁴; Andrew D. Krystal, MD⁵; Kenneth L. Lichstein, PhD⁶; Charles M. Morin, PhD⁷

¹Ryerson University, Toronto, Canada; ²University of Pittsburgh School of Medicine, Pittsburgh, PA; ³University of California San Diego, La Jolla, CA; ⁴Veterans Affairs and Duke University Medical Centers, Durham, NC; ⁵Duke University Medical Center, Durham, NC; ⁶The University of Alabama, Tuscaloosa, AL; ⁷Laval University, Quebec, Canada

Study Objectives: To present an expert consensus, standardized, patient-informed sleep diary.

Methods and Results: Sleep diaries from the original expert panel of 25 attendees of the Pittsburgh Assessment Conference¹ were collected and reviewed. A smaller subset of experts formed a committee and reviewed the compiled diaries. Items deemed essential were included in a Core sleep diary, and those deemed optional were retained for an expanded diary. Secondly, optional items would be available in other versions. A draft of the Core and optional versions along with a feedback questionnaire were sent to members of the Pittsburgh Assessment Conference. The feedback from the group was integrated and the diary drafts were subjected to 6 focus groups composed of good sleepers, people with insomnia, and people with sleep apnea. The data were summarized into themes and changes to the drafts were made in response to the focus groups. The resultant draft was evaluated by another focus group and subjected to lexile analyses. The lexile analyses suggested that the Core diary instructions are at a sixth-grade reading level and the Core diary was written at a third-grade reading level.

Conclusions: The Consensus Sleep Diary was the result of collaborations with insomnia experts and potential users. The adoption of a standard sleep diary for insomnia will facilitate comparisons across studies and advance the field. The proposed diary is intended as a living document which still needs to be tested, refined, and validated.

Keywords: Sleep diary, insomnia, sleep assessment

Citation: Carney CE; Buysse DJ; Ancoli-Israel S; Edinger JD; Krystal AD; Lichstein KL; Morin CM. The consensus sleep diary: standardizing prospective sleep self-monitoring. *SLEEP* 2012;35(2):287-302.

The Consensus Sleep Diary

Consensus Sleep Diary (Please Complete Upon Awakening)
Sample

ID/NAME: _____

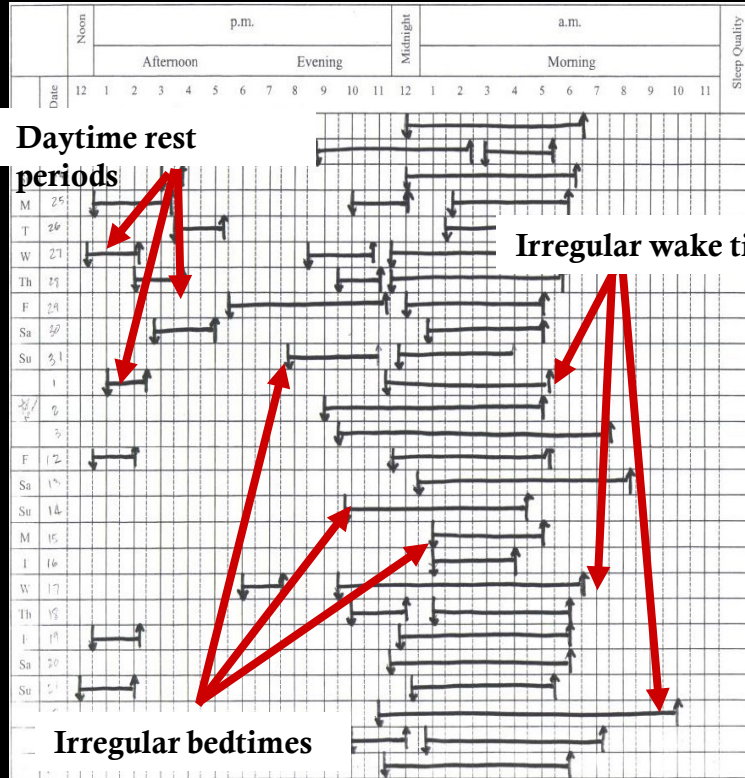
Today's Date	4/5/08							
1. What time did you get into bed?	10:15 p.m.							
2. What time did you try to go to sleep?	11:30 p.m.							
3. How long did it take you to fall asleep?	55 min.							
4. How many times did you wake up, not counting your final awakening?	6 times							
5. In total, how long did these awakenings last?	2 hours 5 min.							
6a. What time was your final awakening?	6:35 a.m.							
6b. After your final awakening, how long did you spend in bed trying to sleep?	45 min.							
6c. Did you wake up earlier than you planned?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No
6d. If yes, how much earlier?	1 hour							
7. What time did you get out of bed for the day?	7:20 a.m.							
8. In total, how long did you sleep?	4 hours							
9. How would you rate the quality of your sleep?	<input type="checkbox"/> Very poor <input checked="" type="checkbox"/> Poor <input type="checkbox"/> Fair <input type="checkbox"/> Good <input type="checkbox"/> Very good	<input type="checkbox"/> Very poor <input type="checkbox"/> Poor <input type="checkbox"/> Fair <input type="checkbox"/> Good <input type="checkbox"/> Very good	<input type="checkbox"/> Very poor <input type="checkbox"/> Poor <input type="checkbox"/> Fair <input type="checkbox"/> Good <input type="checkbox"/> Very good	<input type="checkbox"/> Very poor <input type="checkbox"/> Poor <input type="checkbox"/> Fair <input type="checkbox"/> Good <input type="checkbox"/> Very good	<input type="checkbox"/> Very poor <input type="checkbox"/> Poor <input type="checkbox"/> Fair <input type="checkbox"/> Good <input type="checkbox"/> Very good	<input type="checkbox"/> Very poor <input type="checkbox"/> Poor <input type="checkbox"/> Fair <input type="checkbox"/> Good <input type="checkbox"/> Very good	<input type="checkbox"/> Very poor <input type="checkbox"/> Poor <input type="checkbox"/> Fair <input type="checkbox"/> Good <input type="checkbox"/> Very good	<input type="checkbox"/> Very poor <input type="checkbox"/> Poor <input type="checkbox"/> Fair <input type="checkbox"/> Good <input type="checkbox"/> Very good
10. How rested or refreshed did you feel when you woke-up for the day?	<input type="checkbox"/> Not at all rested <input checked="" type="checkbox"/> Slightly rested <input type="checkbox"/> Somewhat rested <input type="checkbox"/> Well-rested <input type="checkbox"/> Very well-rested	<input type="checkbox"/> Not at all rested <input type="checkbox"/> Slightly rested <input type="checkbox"/> Somewhat rested <input type="checkbox"/> Well-rested <input type="checkbox"/> Very well-rested	<input type="checkbox"/> Not at all rested <input type="checkbox"/> Slightly rested <input type="checkbox"/> Somewhat rested <input type="checkbox"/> Well-rested <input type="checkbox"/> Very well-rested	<input type="checkbox"/> Not at all rested <input type="checkbox"/> Slightly rested <input type="checkbox"/> Somewhat rested <input type="checkbox"/> Well-rested <input type="checkbox"/> Very well-rested	<input type="checkbox"/> Not at all rested <input type="checkbox"/> Slightly rested <input type="checkbox"/> Somewhat rested <input type="checkbox"/> Well-rested <input type="checkbox"/> Very well-rested	<input type="checkbox"/> Not at all rested <input type="checkbox"/> Slightly rested <input type="checkbox"/> Somewhat rested <input type="checkbox"/> Well-rested <input type="checkbox"/> Very well-rested	<input type="checkbox"/> Not at all rested <input type="checkbox"/> Slightly rested <input type="checkbox"/> Somewhat rested <input type="checkbox"/> Well-rested <input type="checkbox"/> Very well-rested	<input type="checkbox"/> Not at all rested <input type="checkbox"/> Slightly rested <input type="checkbox"/> Somewhat rested <input type="checkbox"/> Well-rested <input type="checkbox"/> Very well-rested

Consensus Sleep Diary (Please Complete Before Bed)

ID/NAME: _____

Today's Date	4/5/10							
11a. How many times did you nap or doze?	2 times							
11b. In total, how long did you nap or doze?	1 hour 10 min.							
12a. How many drinks containing alcohol did you have?	3 drinks							
12b. What time was your last drink?	9:20 p.m.							
13a. How many caffeinated drinks (coffee, tea, soda, energy drinks) did you have?	2 drinks							
13b. What time was your last drink?	3:00 p.m.							
14. Did you take any over-the-counter or prescription medication(s) to help you sleep?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No	<input type="checkbox"/> Yes <input type="checkbox"/> No
If so, list medication(s), dose, and time taken	Medication(s): Relaxo-Herb	Medication(s):	Medication(s):	Medication(s):	Medication(s):	Medication(s):	Medication(s):	Medication(s):
	Dose: 50 mg	Dose:	Dose:	Dose:	Dose:	Dose:	Dose:	Dose:
	Time(s) taken: 11 pm	Time(s) taken:	Time(s) taken:	Time(s) taken:	Time(s) taken:	Time(s) taken:	Time(s) taken:	Time(s) taken:
15. Comments (if applicable)	I have a cold							

Visual Sleep Diary

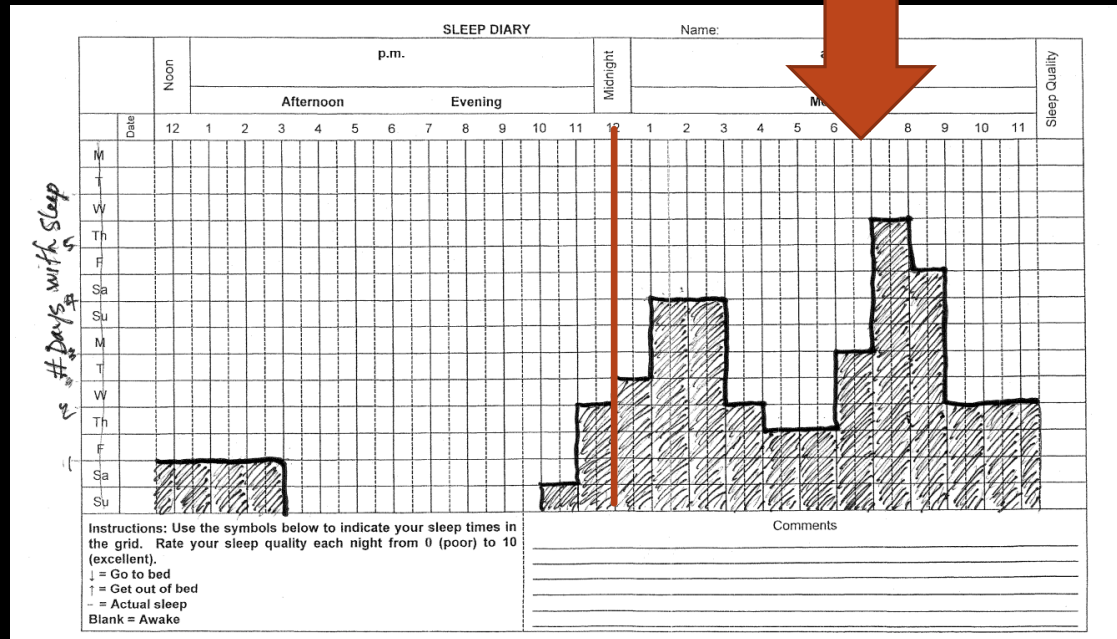
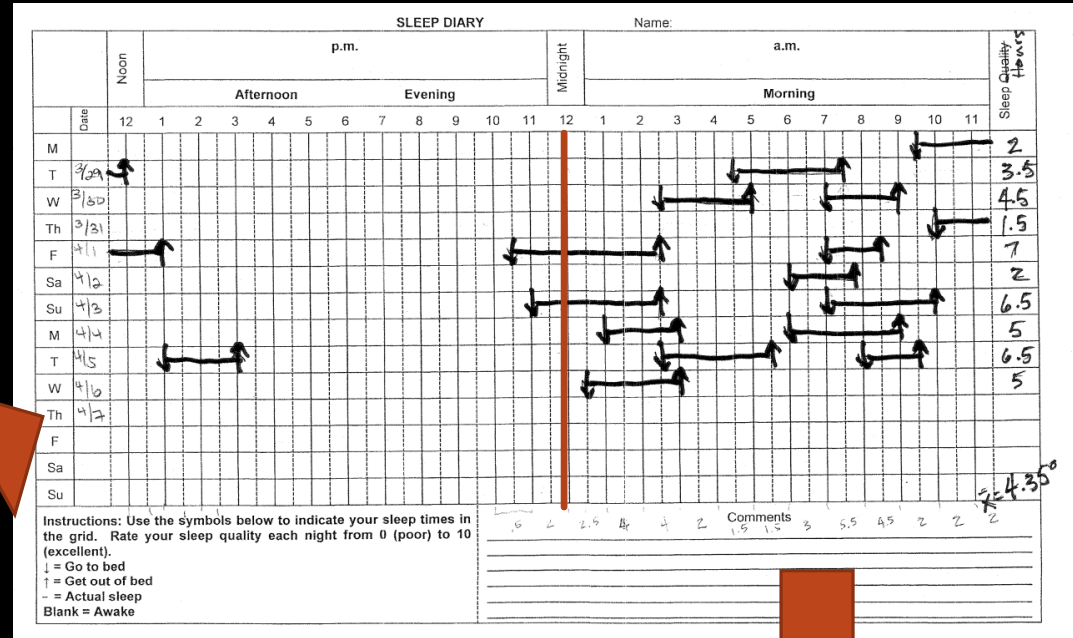


Advantages?
Disadvantages?

Visual Sleep Diary

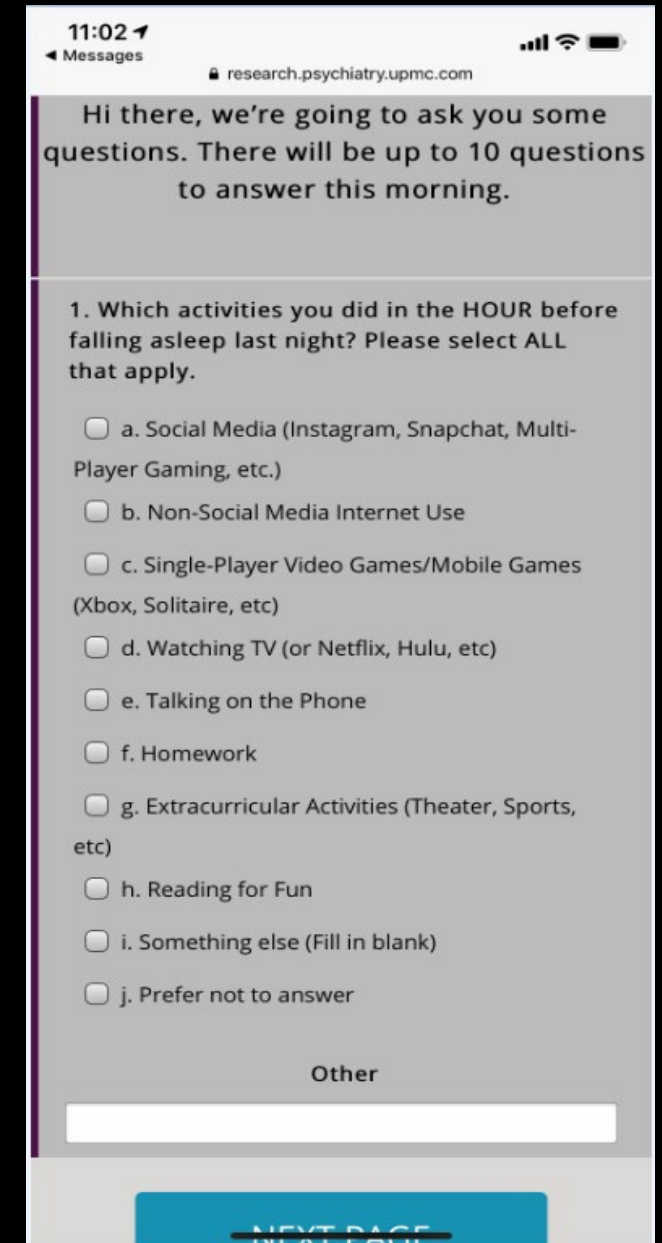
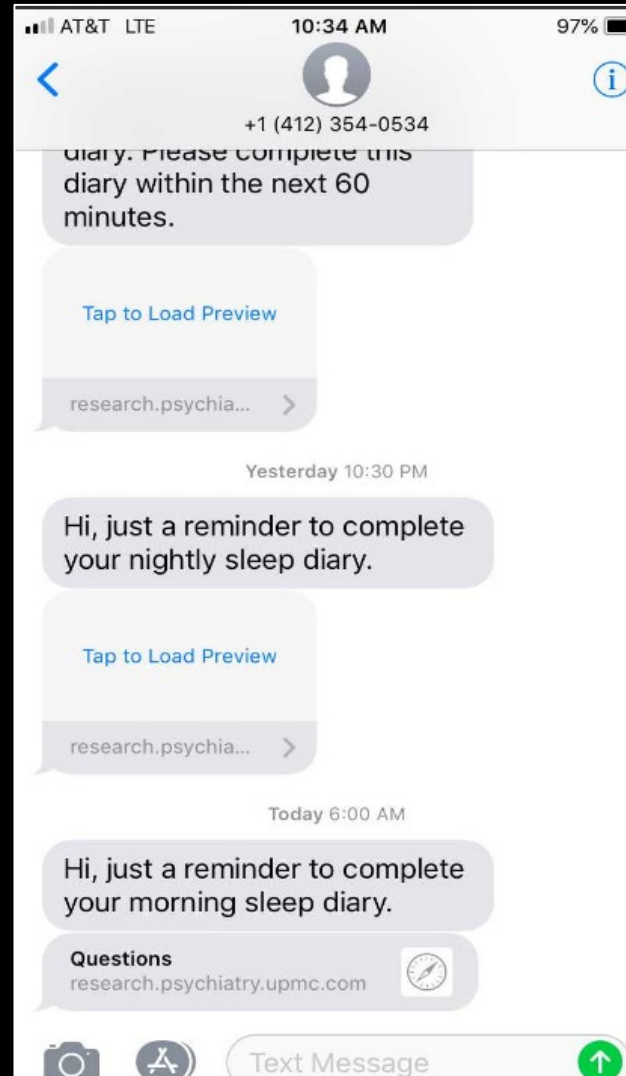
Patient sleep diary

sleep
 on-off sleep
 Tues 3/29/11 9:30 AM to 12:00 PM
sleep
 Wed- 3/30/11- 4:30 AM to 7:35 AM
sleep sleep
 Thu- 3/31/11- 2:30 AM to 5:05 AM 7:00 AM to 9:00 AM
sleep sleep
 Fri- 4/1/11- 10:00 AM to 10:55 PM 10:30 PM to 2:30 AM
sleep
 Sat- 7:00 AM to 8:30 AM
sleep sleep
 Sun- 4/3/11- 6:00 AM to 7:45 AM 11:00 PM to 2:30 AM
sleep sleep
 Mon- 4/4/11- 7:00 AM to 10:00 AM 1:00 AM to 3:00 AM
sleep sleep
 Tues- 4/5/11- 6:00 AM to 9:00 AM 1:00 PM to 3:00 PM
sleep sleep
 Wed- 4/6/11- 2:30 AM to 5:00 AM 8:00 to 9:30 AM
sleep
 Thu- 4/7/11 12:30 AM to 3:00 AM



Mobile Sleep Diary

- ◆ Smartphone-based
- ◆ Morning and evening
- ◆ Times set individually
- ◆ Automatically delivered
- ◆ Reminders if not completed
- ◆ Branching capabilities



Mobile Sleep Diary

2. Did you TRY to fall asleep last night, or did you fall asleep while doing something else (such as, while reading)?

- a. I tried to fall asleep
- b. I fell asleep while doing something else
- c. I prefer not to answer

NEXT PAGE

PREVIOUS PAGE

Last night, I actually tried to go to sleep at:

- Morning (4 AM to 11:59AM)
- Afternoon (12 PM Noon to 4:59 PM)
- Evening (5 PM to 8:59 PM)
- Nighttime (9:00 PM to 3:59 AM)

NEXT PAGE

PREVIOUS PAGE

3. What TIME did you try to fall asleep last night (sometimes called "lights out")?

Hour:

Minute:

NEXT PAGE

PREVIOUS PAGE

4. How many MINUTES did it take you to fall asleep in bed last night?

NEXT PAGE

PREVIOUS PAGE

Mobile Sleep Diary

2. Did you TRY to fall asleep last night, or did you fall asleep while doing something else (such as, while reading)?

- a. I tried to fall asleep
- b. I fell asleep while doing something else
- c. I prefer not to answer

NEXT PAGE

PREVIOUS PAGE

[Need Help? Click Here](#)

Last night, I actually fell asleep at:

- Morning (4 AM to 11:59AM)
- Afternoon (12 PM Noon to 4:59 PM)
- Evening (5 PM to 8:59 PM)
- Nighttime (9:00 PM to 3:59 AM)

NEXT

PREVIOUS PAGE

[Need Help? Click Here](#)

3. What TIME did you fall asleep last night?

Hour:

Minute:

NEXT

PREVIOUS PAGE

Mobile Sleep Diary

6. How many times did you wake up during the night, after you fell asleep?

NEXT PAGE

PREVIOUS PAGE

7. About how many MINUTES were you awake during the night, after you fell asleep?

NEXT PAGE

PREVIOUS PAGE

Mobile Sleep Diary

Today I woke at:

- Morning (4 AM to 11:59AM)
- Afternoon (12 PM Noon to 4:59 PM)
- Evening (5 PM to 8:59 PM)
- Nighttime (9:00 PM to 3:59 AM)

8. What TIME did you wake up this morning?
(If you snoozed this morning, please report the last time you woke up, after snoozing)

Hour:

Minute:

[NEXT PAGE](#)

[PREVIOUS PAGE](#)

[NEXT PAGE](#)

[PREVIOUS PAGE](#)

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9. Today, I finally got out of bed at:

- Morning (4 AM to 11:59AM)
- Afternoon (12 PM Noon to 4:59 PM)
- Evening (5 PM to 8:59 PM)
- Nighttime (9:00 PM to 3:59 AM)

[NEXT](#)

[PREVIOUS PAGE](#)

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9. What TIME did you finally get out of bed? (If you need to change the range of available time, click PREVIOUS)

Hour:

Minute:

[NEXT](#)

[PREVIOUS PAGE](#)

Mobile Sleep Diary

[Need Help? Click Here](#)

10. On a scale of 1 (Very Poorly) to 100 (Very Well), how well did you sleep last night?

Very Poorly Very Well

11. On a scale of 1 (Very Sleepy) to 100 (Very Alert), how did you feel when you started your day today?

Very Sleepy Very Alert

NEXT

PREVIOUS PAGE

Thank you. All your WDX assessments hve been completed

Do you need to talk to someone? Please text HOME to 741741 to text with a counselor. You can also call 911, or the Re:Solve Crisis Network at 1-888-796-8226.

If you would like to receive additional resources or for a treatment referral, please email tapas@upmc.edu or call (412) 246-5963.

Advantages?
Disadvantages?

Questions to Ask Yourself

- ◇ What do you want to use sleep monitoring for?
- ◇ What parameters do you care about?
- ◇ Which factors are most important?
- ◇ Need more studies!

Mobile Sleep Diary

[Need Help? Click Here](#)

2. What time did you have your first contact with another person (in person or by phone)?

: AM PM

: AM PM

NEXT

PREVIOUS PAGE

[Need Help? Click Here](#)

3. What time did you start school or your main activity of the day?

: AM PM

I did not start any activities today

NEXT

PREVIOUS PAGE

[Need Help? Click Here](#)

4. How many caffeinated drinks did you have today? (coffee, tea, soda, pop, energy drink)

NEXT

PREVIOUS PAGE

Mobile Sleep Diary

[Need Help? Click Here](#)

6. Did you take any naps today ON PURPOSE?

Yes

No

Prefer not to answer

NEXT

PREVIOUS PAGE

[Need Help? Click Here](#)

7. For how many MINUTES did you nap?

NEXT

PREVIOUS PAGE

[Need Help? Click Here](#)

8. Today, how many times did you doze off ACCIDENTALLY during regular daytime activities?

NEXT

PREVIOUS PAGE

Mobile Sleep Diary

[Need Help? Click Here](#)

9. What time did you have dinner today?

: AM PM

I did not have dinner today

NEXT

PREVIOUS PAGE

[Need Help? Click Here](#)

10. On a scale of 1 (Very sleepy) to 100 (Very awake), ON AVERAGE how did you feel today?

1 Very Sleepy 100 Very Awake

11. On a scale of 1 (Very poor) to 100 (Very best), ON AVERAGE how was your mood today?

1 Very Poor 100 Very Best

NEXT

PREVIOUS PAGE

[Need Help? Click Here](#)

12. Do you think your sleep LAST NIGHT impacted how you felt or behaved today? (mood, sleepiness, performance at school, sports, extracurriculars, etc)

Yes

No

Prefer not to answer

NEXT

PREVIOUS PAGE

[Need Help? Click Here](#)

13. Which areas do you think last night's sleep affected? Please select ALL that apply.

a. Mood

b. Sleepiness

c. School work

d. Sports or other extracurricular activities

e. Friendships

f. Alertness

g. Physical health

h. Other (Fill in blank)

i. Prefer not to answer

Other

NEXT