A scoping review of sleep discrepancy methodology: what are we measuring and what does it mean?

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# Abstract

## Study Objectives

To examine how past studies have conceptualised sleep discrepancy and identify and evaluate the methods used for its measurement and analysis.

## Method

We searched MEDLINE, Embase, PsycINFO, CINAHL Plus, PubMed, Scopus, and Web of Science in April 2022 for studies comparing self-report and objective measures of sleep. Methodological information was extracted from relevant studies and included measures of self-report and objective sleep, sleep variables (e.g., total sleep time), derived discrepancy indices (e.g., difference scores), handling of repeated measurements, and methods of measure comparison (e.g., Bland-Altman analyses).

## Results

Two hundred and forty-four relevant records were identified. Studies varied according to objective sleep measure; actigraphy algorithm, software, and rest interval; polysomnography setting and scoring criteria; sleep variables; self-report sleep measure; number of nights of objective recording; time frame of self-report measure; self-report sleep variable definition; sleep discrepancy derived index; presence and handling of repeated measurements; and statistical method for measure comparison.

## Conclusions

Sleep discrepancy was mostly conceived as discordance in sleep states or sleep time variables, and various forms of this discordance differed in their conceptual distance to sleep misperception. Furthermore, studies varied considerably in methodology with critical conceptual and practical implications that have received little attention to date. Substantive methodological issues were also identified relating to the use of derived indices for operationalising sleep discrepancy, defining objective sleep onset latency, calculating actigraphy rest intervals, measuring correlation and concordance, averaging sleep variables across nights, and defining sleep quality discrepancy. Solutions and recommendations for these issues are discussed.

## Key words

Sleep discrepancy; sleep misperception; scoping review

## Statement of Significance

Sleep discrepancy, the discordance between self-report and objective measures of sleep, is an important fea- ture for theory in insomnia and a key issue in sleep measurement. Despite the considerable research in this area, the status of sleep discrepancy as a concept is unclear and varied methodologies are employed with unknown theoretical or conceptual implications. This scoping review integrates a comprehensive range of methodological details from sleep discrepancy studies, clarifying the concept of sleep discrepancy and critically evaluating approaches to its measurement. The broad view of the literature afforded by the sys- tematic search allows us to identify and discuss conceptual and methodological issues that have received little attention and are critical for the advancement of research in sleep discrepancy.

# Introduction

Sleep is measured in two principal ways: objectively through polysomnography or actigraphy, and by self- report through questionnaires or sleep diaries. The discordance that can exist between these two forms of measurement is known as subjective-objective sleep discrepancy, or more simply, sleep discrepancy. Sleep discrepancy is a common feature of insomnia disorder, where it is also referred to as sleep misperception or paradoxical insomnia. Individuals with insomnia tend to underestimate total sleep time (TST), and overestimate sleep onset latency (SOL) and wake after sleep onset (WASO) relative to objective measures (Baglioni et al., 2014; Edinger & Fins, 1995; Means, 2003) and are more likely to report prior wakefulness after being woken in laboratory studies (Mendelson et al., 1986; Mercer et al., 2002).

Sleep discrepancy has been investigated with diverse methods for its conceptualisation and measurement, such that it can be diﬀicult integrate findings across studies. For example, sleep discrepancy may be con- sidered as a spectrum (Trajanovic et al., 2007), ranging from positive (self-report exceeds objective) to negative (objective exceeds self-report), or as a measure of absolute sleep agreement (Baillet et al., 2016). Any number of sleep variables such as TST, SOL, or WASO can used to operationalise sleep discrepancy, each differing conceptually and carrying varying theoretical implications. Sleep discrepancy may even be considered beyond these sleep time-based metrics and represent discordance in self-report and objective sleep patterns (Al Lawati et al., 2021), or sleep quality. Sleep discrepancy can be characterised in a sample by directly comparing self-report and objective sleep with a range of statistical techniques. Other studies may derive variables to define sleep discrepancy quantitatively to measure its relationship with other variables, for example using a difference score of self-report TST – objective TST.

To date, there have been few systematic attempts to synthesise or evaluate the varied approaches to investi- gating sleep discrepancy. Three reviews have been conducted in this area. Castelnovo et al. (2019) conducted a systematic review of quantitative definitions of paradoxical insomnia, an insomnia subvariant defined, in part, by the presence of sleep discrepancy. This excluded studies where sleep discrepancy was not used to form diagnostic criteria. Two subsequent reviews were conducted by Rezaie et al. (2018) and Stephan et al. (2023) focussing on paradoxical insomnia and the correlates of sleep misperception, respectively. Whilst informative discussions of research findings, these studies excluded a focus on concepts or methodology.

Consequently, sleep discrepancy remains an ambiguous construct, with conceptual and methodological sources of variation that are yet to be formally delineated. This threatens the development of theory in research areas such as insomnia as it can be unclear whether sleep discrepancy studies are measuring or operationalising the same or different phenomena. The replicability of findings can also be affected where proliferation of varying analysis strategies introduces uncertainty into the data analysis process (Hoffmann et al., 2021). Research is needed to integrate and evaluate the varied approaches to sleep discrepancy, clarify its conceptual boundaries, and facilitate comparisons across studies.

A scoping review is a method of research synthesis that aims to map existing literature in a field of interest and identify types of evidence available in a given topic (Arksey & O’Malley, 2005). We used a scoping review strategy to examine how sleep discrepancy has been conceptualised in the literature and identify and evaluate the methods used to investigate it. A preliminary search of MEDLINE (Ovid), the Cochrane Library, Embase (Ovid), and PsycINFO (Ovid) was conducted to identify existing or in-progress systematic or scoping reviews on the topic. Except for the three reviews mentioned above, no records were identified.

# Methods

## Protocol and registration

The review was conducted according to guidelines provided by the JBI scoping review methodology group (Peters et al., 2020) and reported according to the Preferred Reporting Items for Systematic reviews and Meta- Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist (Tricco et al., 2018). A review protocol was registered with the Open Science Framework on April 4, 2022 (doi: 10.17605/OSF.IO/BCJNQ), prior to conducting searches. Deviations from the protocol are outlined in the appendices ([11.2](#_bookmark26)).

## Eligibility criteria

Participants of all age groups and clinical populations were included in the review. To adequately map the boundaries of sleep discrepancy as a concept, we included any study that compared an objective measure of sleep (e.g., polysomnography, actigraphy) with an equivalent self-report measure of sleep (e.g., sleep diaries, questionnaires), through statistical analysis or derived indices. Any measure of self-report and objective sleep was considered including indices of sleep time such as TST, SOL, and WASO, in addition to measures of sleep quality, sleep patterns, or any other sleep-related experience or behaviour.

## Exclusion criteria

Studies were excluded that (i) made no direct comparisons between equivalent self-report and objective sleep measures, (ii) included informant, rather than self-report measures, (iii) were case reports or review articles,

(iv) were limited to self-report or objective measures not related to sleep, (v) contained no empirical data,

(vi) omitted either a self-report or equivalent objective measure of sleep, or (vii) were a grey literature source including theses, dissertations, and conference abstracts. No records were excluded on the basis of geographic location, cultural factors, or any other contextual feature.

## Search strategy

The search strategy aimed to identify articles published in peer-reviewed journals and, initially, grey literature including theses, dissertations, and conference abstracts. Due to the large number of records returned by initial searches, grey literature was excluded at the full text extraction stage. The following databases were searched: MEDLINE (Ovid), Embase (Ovid), PsycINFO (Ovid), CINAHL Plus, PubMed, Scopus, Web of Science, ProQuest Theses and Dissertations, and OSF Preprints. The search strategy included keywords, index terms, and search operators adapted for each database. Searches across all databases were conducted on the 24th April 2022. The full search strategy for Embase (Ovid) is provided as an example in Table [1](#_bookmark0) below. See Appendix A for full search strategies for other databases.

## Sources of evidence selection

Records identified from searches were exported to EndNote 20 (The EndNote Team, 2013) for collation and then uploaded to Rayyan (Ouzzani et al., 2016) for deduplication and title and abstract screening. Two independent reviewers (TW and SF) screened titles and abstracts to identify studies for full-text retrieval using the inclusion criteria. Percentage of agreement between reviewers was 87.6% and conflicts were resolved via discussion. The full-texts of articles passing title and abstract screening were screened by TW with reasons for exclusion reported. Due to the unanticipated size of the literature, articles from sources other than peer-reviewed journals were added to exclusion criteria post-hoc.

## Charting the data

Data extraction was performed by TW. Methodological features of included articles were selected on their po- tential influence on the measurement or operational definition of sleep discrepancy and included the following: objective sleep measure type/hardware, actigraphy algorithm, software, and rest interval, polysomnography setting and scoring criteria, self-report sleep measure, sleep variables (e.g., TST, WASO etc…) and definitions

Table 1: Search strategy for Embase (Ovid)

Step Terms and Operators Records

1. sleep discrepancy or paradoxical insomnia or subjective insomnia or (sleep adj2 misperception).mp
2. ((self report\* or diary or subjective\*) and (objective\* or actigraph\* or polysomnograph\* or polygraph\*)).mp.

488

193243

1. (exp polysomnography/ or exp actimetry/) and exp self report/ 1676
2. (sleep\* and (”over estimat\*” or ”over report\*” or ”under estimat\*” or ”under report\*” or overestimat\* or overreport\* or underestimat\* or underreport\* or discrepan\* or concordan\* or agreement or disagreement or discordan\* or congruen\* or incongruen\*)).mp.

9362

1. 2 or 3 193302
2. 4 and 5 1234
3. 1 or 6 1569

thereof, methods of handling repeated measurements, methods of comparing self-report and objective sleep within groups, and methods for operationalising sleep discrepancy to investigate its relationship with other variables.

## Data items

Extracted data items numbered in the hundreds and are described comprehensively in the codebook available at: <https://github.com/tfwalton/sleep-discrepancy-review/raw/main/codebook.xlsx>.

## Synthesis of results

This manuscript, including all tables and figures summarising data were generated using computationally reproducible methods (Lindsay, 2023; Piccolo & Frampton, 2016) in R version 4.4.0 (2024-04-24 ucrt) (R Core Team, 2023), with R Studio (Posit team, 2024) and R Markdown (Allaire et al., 2023). Packages used in the code for this manuscript include tidyverse (Wickham et al., 2019), bookdown (Xie, 2023a), knitr (Xie, 2023b), kableExtra (H. Zhu, 2023), english (Fox et al., 2021), and DiagrammeR (Iannone, 2023). All code and data are available through the Github repository: <https://github.com/tfwalton/sleep-discrepancy-review>.

# Results

The initial search of databases returned 6,190 from which 3,903 duplicate articles were removed. Details of the review process from article identification, screening, and selection are available in the PRISMA flowchart depicted in Figure [1](#_bookmark1) below.



Duplicate records removed (n = 3,894)

Records identified from Embase (n = 1,569) PsycINFO (n = 471) MEDLINE (n = 875)

PubMed (n = 761) CINAHL Plus(n = 310) SCOPUS (n = 826)

Web of Science (n = 1,288)

Proquest Theses and Dissertations Global (n = 90)

Records excluded (n = 1,641)

Records screened (n = 2,296)

Reports sought for retrieval (n = 655)

Figure 1: PRISMA flowchart



Reports assessed for eligibility (n = 655)

Reports excluded (n = 411)

No direct comparisons between equivalent parameters (n = 43) Informant report only (n = 36)

Duplicate (missed at deplication stage; n = 11) Case report (n = 10)

Self-report or objective measures not related to sleep (n = 2) Review article (n = 5)

Not empirical study (n = 12)

Article in language other than English (n = 19)

Either self-report or objective measure not included (n = 1) Grey literature source (n = 272)

Total studies included in review (n = 244)

## Article characteristics

A total of 248 studies were identified from 244 records, with 4 records reporting two studies or experiments within a single text. Records spanned 32 countries, with the majority originating from the USA (n = 96).

Sample sizes for studies ranged from 8 to 8,438 (median = 66, IQR = 119.5). Most studies included both sexes in their samples (n = 229), whereas 8 and 11 comprised only males or females, respectively. Most studies contained samples of adults of all ages (n = 197). Others reported specific age groups: older adults (n = 23), younger adults (n = 14), adolescents (n = 8), and children (n = 6). Sample characteristics for studies are included in Figure [2](#_bookmark2). For a full list of article characteristics, see the appendices ([5](#_bookmark27))

normative insomnia referred for PSG

depression post−traumatic stress disorder

bipolar disorder fibromyalgia

obstructive sleep apnoea paradoxical insomnia

pregnancy psychophysiological insomnia traumatic brain injury

chronic fatigue mild cognitive impairment

schizophrenia sleep disorders alcohol dependence Alzheimers disease

breast cancer comorbid fibromyalgia and insomnia failed back surgery syndrome

HIV

poor sleep sleep complaint substance−use visual impairment acupuncture

Sample characteristics

athletes caregivers

chronic musculoskeletal pain

chronic pain COVID−19 lockdown

CPAP users delayed sleep−wake phase disorder excessive daytime sleepiness excessive daytime somnolence

firefighters heart failure insomnia symptoms intensive care unit

interstitial lung disease

kidney disease lung cancer multiple sclerosis

narcolepsy opioid use disorder

osteoarthritis overweight/obese postmenopausal women premenopausal women

prostate cancer psychiatric inpatients rotator cuff tears

shiftwork subjective insomnia survivors of childhood cancer

type−II diabetes

78

54

19

8

8

7

6

5

5

5

4

4

3

3

3

3

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2

2

2

2

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1

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1

1

1

1

1

1

0 20 40 60 80

Number of studies

Figure 2: Sample characteristics

## Methodological features

### Measures of objective sleep

Objective methods of recording sleep formed two major groups: EEG-based methods and movement-based methods. See Figure [3](#_bookmark3) for number of studies using each method. All movement-based methods involved tri-axial accelerometry through actigraphs or similar devices. PSG was the predominant EEG-based method (n = 106), however a handful of studies used EEG alone, in either single channel (n = 2), standard (n = 4), or high-definition formats (n = 3). A single study used a method of sleep recording that involved recording verbal responses from participants elicited by soft tones played at intervals throughout the night (Espie et al., 1989).

Movement (including actigraphy)

143

116

EEG (including PSG)

0 50 100 150

Number of studies

Figure 3: Measures of objective sleep

* + - 1. **Polysomnography** Methodological features charted for PSG included scoring criteria, setting, and recording period. See Figure [4](#_bookmark4) for scoring criteria of included studies.

R&K AASM

56

45

1

1

1

5

Scoring Criteria

Oxford screen scoring method

R&K and Mendelson SS90−III Sleep Stager System

Criteria not reported

0 20 40

Number of studies

Figure 4: PSG scoring methods

Methods for scoring PSG were mostly divided between American Academy of Sleep Medicine (AASM) and Rechtschaffen & Kales (R&K) guidelines. Rogers et al. (1993) used an automated system for sleep staging, the SS90-III Sleep Stager System (Oxford Medicals, Oxford). Vanable et al. (2000) used Mendelson’s (2012) guidelines in addition to R&K. Edinger (1995) used combined audio and visual criteria for sleep staging (1989). Settings for PSG varied and are depicted in Figure [5](#_bookmark5).

In−lab Home−based

86

18

3

1

1

1

2

In−lab & home−based

Setting

fMRI

Airline rest facility

Truck−berth PSG setting not reported

0 25 50 75

Number of studies

Figure 5: PSG setting

In-lab and home-based tests comprised the substantial majority of PSG settings with a handful of more unusual settings noted. As for recording periods, PSG most often occurred during the night although a number of alternative periods were noted. See Figure [6](#_bookmark6) for a depiction of PSG recording periods.

Nocturnal

98

3

1

1

1

1

1

1

MSLT

24−hour Daytime nap Nocturnal nap In−flight / layover Nocturnal & MSLT

Period

Repeated naps across 28−hour period

0 30 60 90

Number of studies

Figure 6: PSG recording period

*Note.* MSLT refers to the multiple sleep latency test.

* + - 1. **Actigraphy** We recorded features of actigraphy including device name, scoring algorithm, soft- ware, and rest interval definition. See Table [6](#_bookmark28) in the appendices for full tabulations of actigraphy characteris- tics. Actigraphy scoring algorithms are responsible for determining wakefulness and sleep from accelerometer- derived motor activity. Scoring algorithms varied across studies and included Actiware (Boyne et al., 2013), MotionWare (CamNTech, UK), SenseWear (Lopez et al., 2018), Domino Light (Gorny et al., 1996), Cole- Kripke (Cole et al., 1992), Kripke (Kripke et al., 1978), Sadeh (Sadeh et al., 1994), Actiheart (Barreira et al., 2009), Fitbit (Jean-Louis et al., 2001), UCSD (Jean-Louis et al., 2001), ActiLife (Peach et al., 2014), Actillume (Jean-Louis et al., 2001), Micro-Electro-Mechanical-Systems (Dunne et al., 2013), Sleep Sign Act (Kissei Comtec Co, Japan), IM Systems (Individual Monitoring Systems, Inc., UWA), Machine Learning Alogrithms (John et al., 2019), Fatigue Science (Russell et al., 2000), Barouni (Barouni et al., 2020), Choi (L. Choi et al., 2011), Tudor-Locke (Tudor-Locke et al., 2014), and Troiano (Troiano et al., 2008). The frequencies of these algorithms are depicted in Figure [7](#_bookmark7).

Actiware Cole−Kripke

54

32

11

5

3

3

2

2

2

1

1

1

1

1

1

1

1

1

1

1

1

1

25

Sadeh UCSD

SenseWear MotionWare

Webster's rescoring rules

IM Systems

Fitbit Tudor−Locke

Algorithm

Troiano Sleep Sign Act Micro−Electro−Mechanical Systems Machine learning algorithm

Kripke Fatigue Science Domino Light

Choi Barouni Actillume ActiLife Actiheart

Algorithm not reported

0 20 40 60

Number of studies

Figure 7: Actigraphy algorithms

Studies using Actiware algorithms varied in their selection of thresholds for scoring wakefulness. These are depicted in Figure [8](#_bookmark8) below.

All thresholds (Low, Medium, High)

3

3

28

3

1

16

80 activity counts (High) 40 activity counts (Medium) 20 activity counts (Low)

Actiware threshold

10 activity counts (Low) Actiware wake threshold not reported

0 10 20

Number of studies

Figure 8: Actiware algorithm threshold settings

The rest interval in actigraphy is the period of time where activity is assessed for sleep and is usually intended to coincide with the time the wearer is in bed, attempting to sleep. Information used to define rest intervals varied across reviewed studies and included, singly or in combination, are depicted below in Figure [9](#_bookmark9).

Sleep diary Event marker press

60

29

21

16

11

10

2

1

1

1

1

42

Manual judgements of activity

Light sensor External parameters such as set bed and rise times

Rest interval

Automatic scoring Discrepancies queried Audiofile timestamps Pressure sensitive pad Scorer blind to diary

Heart rate Rest interval not reported

0 20 40 60

Number of studies

Figure 9: Methods for defining rest intervals in actigraphy

The precise combination and order of priority of methods in each study varied markedly. See Table [6](#_bookmark28) in the appendices for qualitative descriptions of rest interval approaches across reviewed studies. “Discrepancies queried” indicates that discrepant sleep diary and actigraphy bed and wake times were queried directly with participants and adjusted following discussion.

### Measures of self-report sleep

Self-report sleep measures comprised seven major types. See Figure [10](#_bookmark10) for the number of studies including each of these.

Sleep diary (including the consensus sleep diary)

102

10

Sleep diary

Graphical sleep diary

Questionnaire on awakening

75

4

1

Interview on awakening

Query on awakening

Graphical response on awakening

Pittsburgh Sleep Quality Index (PSQI)

37

17

Habitual sleep questionnaire

Habitual sleep questionnaire (other than PSQI)

0 25 50 75 100 125

Number of studies

Figure 10: Measures of self-report sleep

Sleep diaries and questionnaires on awakening were the most common measure of self-report sleep, followed by habitual sleep questionnaires including the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989). Note, habitual sleep refers to questionnaires that require participants to provide global judgements about their sleep that correspond to a period of time longer than a single night such as a week or a month. Graphical response formats for sleep diaries and questionnaires on awakening required participants to draw their sleep on scales comprising discrete blocks of time. We also recorded whether self-report measures overall attempted to capture habitual sleep or rather *episodic* sleep that occurred night-by-night/episode-by-sleep episode at the same time as objective measures. Results are depicted in Figure [11](#_bookmark11) below.

Habitual sleep

51

7

187

Habitual and episodic sleep

Episodic sleep

0 50 100 150

Number of studies

Figure 11: Habitual or episodic sleep

## Sleep variables

A range of variables were used to operationalise sleep discrepancy. These are listed below in Figure [12](#_bookmark12).

Total sleep time (TST)

197

142

73

65

21

27

7

5

13

19

14

2

2

6

4

3

2

1

1

1

1

Sleep onset latency (SOL)

Wake after sleep onset (WASO)

Sleep efficiency (SE)

Time in bed (TIB)

Number of awakenings (NWAK)

Total wake time (TWT)

Sleep period time (SPT)

Sleep onset time (SOT)

Final wake time (FWT)

Sleep variable

Bed time (BT)

Rise time (RT)

Sleep midpoint

Binary Sleep−Wake agreement

Confusion Matrix Sleep−Wake agreement

Latency to persistent sleep (LPS)

Sleep during subjective latency (SDSL)

Latency−adjusted total sleep time (LA−TST)

Effective sleep time (EST)

Subjective wake time (SWT)

Intermittent wake time (IWT)

0 50 100 150 200

Number of studies

Figure 12: Sleep variables

*Note.* TST was considered equivalent to sleep duration in this review. Calculation of TST and SE varied across studies in both objective and self-report form. SOL (also referred to as sleep latency; SL) varied only in its objective form whilst WASO varied only in its self-report form. TIB was calculated as the time between bedtime BT and RT. BT and and polysomnographic lights off time for PSG studies were considered equivalent in this review. RT was considered equivalent to actigraphic sleep offset and polsomnographic lights on. Sleep mid-point was calculated as (FWT–BT)/2. LPS was defined as latency to 10 minutes of uninterrupted sleep. SDSL was defined objective total sleep time following the point of subjective sleep onset. EST was defined as TST–WASO–SOL. SWT was defined as WASO + SOL. TWAK was defined as the length of time between RT and FWT. No definition was reported for IWT. Binary sleep-wake involved measuring at one or multiple instances whether a participant’s reported sleep state matched the objective sleep state upon which the query was conditional (e.g., participants were only queried during objectively-confirmed sleep). On the other hand, confusion matrix sleep-wake involved measuring at one or multiple instances whether a participant’s reported sleep state matched an objective sleep state that was allowed to vary independent of the query (e.g., participants were queried at a certain time point irrespective of sleep state). The states were called so as the former approach produces a binary outcome whereas the latter produces a confusion matrix.

The sleep variables TST, SOL, WASO, and SE were most common and formed the majority of identified parameters. Direct sleep-wake agreement was measured by a small subset of studies. Almost all identi- fied sleep variables were measures related to sleep time or awakenings, although we did note some more unconventional parameters listed below separately from the figure above. Allawati et al. (2021) compared self-report and actigraphic measures of sleep patterns including monophasic, biphasic dawn, biphasic siesta, and polyphasic. Lockley et el (1999), Dautovich et al. (Dautovich et al., 2008), Hanisch et al. (Hanisch et al., 2011), and Nguyen-Michel et al. (Nguyen-Michel et al., 2015) reported discrepancy for naps specifically, including variables such as number of naps, number of days napped, mean duration of naps, and total nap time. Baek et al. (2020) and Chan et al. (2018) compared self-report and actigraphic assessments of variabil- ity in TST and other sleep parameters. Thun et al. (2012) compared self-report and actigraphic measures of morningness-eveningness. Finally, McIntyre et al. (2016) investigated self-report-objective discrepancy across a range of sleep behaviours including position at sleep onset, position at wake, number of positional changes, and the presence of leg twitches or jerks.

### Self-report sleep variable definitions

Calculation of self-report TST, WASO, SE, and TIB varied across studies. Variations across three major types of self-report TST were observed: TST queried directly (e.g., “how many minutes did you sleep last night”, TST calculated from other parameters such as TIB, SOL, and WASO, and TST calculated from graphical responses. The results for TST definitions are depicted in Figure [13](#_bookmark13) below.

Direct query

122

18

4

1

2

1

3

5

7

33

TIB−−SOL−−WASO−−TWAK

TIB−−TWT TIB−−WASO

Variable definitions

FA−−LO

FWT−−SOT

SPT−−SOL−−WASO

Calculated (calculation not reported)

Graphical responses

Not reported

0 50 100

Number of studies

Figure 13: Self-report TST definitions

*Note.* FA–LO indicates lights off to final awakening. By conventional definitions of SPT, SPT–SOL–WASO is equal to TIB–SOL–WASO–TWAK, but is listed separately above to reflect differences in terminology. Definitions for WASO also varied and these are depicted in [14](#_bookmark14) below.

Direct query TIB−−TST−−SOL

39

2

1

1

3

30

Variable definitions

Number of awakenings \* average length of awakenings

Calculated (not reported) Graphical responses Definition not reported

0 10 20 30 40 50

Number of studies

Figure 14: Self-report WASO definitions

Definitions for self-report TIB used in operationalising sleep discrepancy are depicted Figure [15](#_bookmark15).

RT−−LO FA−−LO

46

4

1

1

1

12

Variable definitions

TST + WASO + SOL

Graphical responses

Direct query Definition not reported

0 10 20 30 40 50

Number of studies

Figure 15: Self-report TIB definitions

*Note.* RT–LO refers to the time between lights off and rise time. SE was almost unanimously calculated as TST/TIB\*100 , although varying definitions for the TST and TIB components affect this outcome. One study (Neu et al., 2007) used two definitions of SE, one comprising TST/TIB and the other TST/sleep period time (SPT).

### Objective sleep variable definitions

Objective TST was defined very consistently with the exception of Sinclair et al. (2014) who, in addition to providing a standard definition for TST, measured TST across a 24-hour period, such that time spent asleep outside the usual nocturnal period (i.e., naps) contributed to this measurement. Objective definitions for SOL varied considerably and these are depicted in Figure [16](#_bookmark16) below.

Actigraphy−defined

71

26

22

8

6

2

1

1

1

1

1

1

1

1

1

1

6

First epoch of any sleep stage (standard AASM) First 3 consecutive epochs of stage 1 or first epoch of any

other sleep (R&K)

First epoch Stage 2

First 20 consecutive epochs any stage of sleep (LPS)

First sleep spindle

First epoch Stage 1

First epoch SWS

SOL definition

First 3 consecutive epochs of sleep

First 2 consecutive epochs of Stage 2

First 10 consecutive epochs Stage 2 First Stage 2 interrupted by no more than 4 epochs of wake

or Stage 1 within 20 epochs

First 20 epochs of sleep containing no more than 4 epochs of wake time, Stage 1 sleep, or movement time

First 20 epochs of Stage 2 or SWS without intervening period of >4 epochs Stage 1 or wakefulness

Video observation

Parameter varied in model

SOL definition not reported

0 20 40 60 80

Number of studies

Figure 16: SOL definitions

*Note.* SWS = slow wave sleep, LPS = latency to persistent sleep, AASM = American Academy of Sleep Medicine guidelines, R&K = Rechstaffen & Kales guidelines. Parameter varied in model indicates that the definition of sleep onset was varied within the context of a predictive model. Among PSG studies, the two most common approaches were dependent on standard definitions provided by the R&K (Rechtschaffen & Kales, 1968) and AASM (Berry et al., 2012) scoring guidelines.

Most studies used standard PSG or actigraphy criteria for defining objective number of awakenings (i.e., a single epoch of wakefulness). A single exception was Lewis et al. (1969), who stipulated that a period last over a minute to count as an awakening. Neu et al. (2007) used the same definitions for objective SE as they did for self-report SE.

### Sleep quality

Sleep quality discrepancy was measured by 14 studies using (on the self-report side) sleep quality ratings (n

= 8), PSQI total scores (n = 3), sleep quality factor scores (n = 1), sleep depth ratings (n = 1), or sleep quality composite scores (n = 1). On the objective side, sleep quality measures included SE (n = 7), factor

scores from sleep variables (n = 2), sleep architectural variables (n = 7), N3 sleep quantity (n = 1), TWT (n = 1), and a composite variable formed from SOL, WASO, and SE (n = 1). Although approaches varied substantially, the most common combination of sleep quality measures was a sleep quality rating and SE.

## Method of handling repeated measurements

Sleep data often involves repeated measurements of the same individual. Actigraphy and sleep diaries usually involve data collection across 7 to 14 days and multiple consecutive nights of PSG are sometimes recorded. Methods for handling repeated measurements are depicted below in Figure [17](#_bookmark17)

Mean values

96

2

1

12

1

13

10

1

1

1

13

8

75

Modal values

Median values

Method of handling repeated measurements

Means of derived indices

Standard deviations of derived indices

Repeated measures ANOVA

Linear mixed models

Generalised estimating equations

Structural equation modelling

Repeated measures correlation

Pooled observations

Separate analyses

Single recording instance

0 25 50 75 100

Number of studies

Figure 17: Methods for handling repeated measurements

*Note.* pooled observations involved collapsing data across multiple instances of recording. Separate analyses indicate that analyses were conducting separately for each instance of recording. In addition to the above, some studies measuring naturalistic sleep in the home environment took day of week into consideration for analyses. Three studies calculated a weighted average for sleep variables equal to 5/7\* (mean weekday sleep)

+ 2/7\* (mean weekend sleep), and 9 performed analyses for weeknights and weekends separately.

## Direct comparisons of self-report and objective sleep

A total of 172 studies measured sleep discrepancy at the group level by directly comparing self-report and objective sleep. Methods for achieving this varied and are depicted below in Figure [18](#_bookmark18)

Pearson or Spearman correlations

96

59

52

20

15

13

10

9

7

3

2

2

2

2

8

Bland Altman Analyses Paired t−tests or Wilcoxon Signed Rank tests

ANOVA

Methods for direct sleep comparisons

Linear models Intraclass Correlation Cohen's Kappa

Classification performance measures 1−sample t−tests of difference scores

Chi−square tests Measures of estimation (e.g., mean bias, typical error of estimate)

Pitman's tests Lin's Concordance Coefficient Independent samples t−tests

Other direct comparison (described below)

0 30 60 90

Number of studies

Figure 18: Statistical methods for comparing self-report and objective sleep

*Note.* Bland Altman analyses include Bland Altman plots and the reporting of 95% limits of agreement (Bland & Altman, 1999). Pitman’s test (also known as the Pitman-Morgan test) is a test of differences of variances between dependent samples (Morgan, 1939; Pitman, 1939) and was used to compare the variability of self-report and objective sleep. One-sample *t*-tests of difference scores are equivalent to paired *t*-tests but are included separately in the figure to reflect differences in reporting. Classification performance measures include percentage agreement, accuracy, sensitivity, specificity, positive predictive value (PPV), and nega- tive predictive value (NPV). Formulae used for the intra-class correlation coeﬀicient varied across studies. Spearman correlations and Wilcoxon Signed Rank Tests were often used to handle the skew of variables such as SOL and WASO. Other methods included the delta coeﬀicient (Girschik et al., 2012), partial cor- relation and factor analysis (Regestein et al., 2004), errors-in-variables regression (Lauderdale et al., 2008), repeated measures correlation (Gibson et al., 2023), non-parametric limits of agreement (Thurman et al., 2018), survival agreement (Guedes et al., 2016), latent correlations for testing associations at within-subjects and between-subjects level (Feng & Svetnik, 2018), and structural equation modelling (Friedmann et al., 2022).

## Methods for investigating the relationship of sleep discrepancy with other variables

A total of 133 studies aimed to investigate the relationship of sleep discrepancy with other variables of interest. Most studies achieved this by operationalising sleep discrepancy on the individual level through the calculation of a derived index.

### Derived indices

Approximately half (n = 128) of included studies calculated a derived index (e.g., self-report TST–objective TST) to operationalise sleep discrepancy. Some studies used indices directly in statistical analyses (n = 107) whilst others used indices to divide samples into groups (n =18) either dichotomising (n = 12) or trichotomising (n = 6) derived score values. Methods for deriving indices varied across studies and can be

broadly categorised into four groups: arithmetic difference scores, where one measure is simply subtracted from the other (e.g., sTST–oTST); absolute difference scores, composed of the absolute value of algebraic dif- ference scores (e.g., |sTST–oTST|); ratio scores, when one measure is divided by the other (e.g., sTST/oTST); and combination scores that incorporate both subtraction and division of component measures (e.g., oTST– sTST/oTST). A list of indices including the number of studies that used them are provided in Figure [19](#_bookmark19) below.

sTST−oTST sSOL−oSOL sWASO−oWASO oTST−sTST sSE−oSE oSOL−sSOL oWASO−sWASO

48

39

17

12

9

8

7

5

4

3

2

2

2

1

1

1

1

Arithmetic difference scores

oSE−sSE

sAwakenings−oAwakenings

sTWT−oTWT sSPT−oSPT sSOT−oSOT sLPS−oLPS sTIB−oTIB sIWT−oIWT sFWT−oFWT sBT−oBT

|sTST−oTST|

7

3

1

1

1

Absolute difference scores

|sSOL−oSOL|

|sWASO−oWASO|

|sSPT−oSPT|

|sSE−oSE|

(sTST/oTST)\*100

15

6

6

4

3

3

2

1

1

1

sTST/oTST sSOL/oSOL (sSOL/oSOL)\*100 sWASO/oWASO (sWASO/oWASO)\*100

Ratio scores

(sSE/oSE)\*100 sTWT/oTWT sTIB/oTIB sSE/oSE

(oTST−sTST)/oTST (sTST−oTST)/oTST\*100 (sTST−oTST)/oTST (sWASO−oWASO)/oWASO\*100 (sSOL−oSOL)/oSOL\*100 (sSE−oSE)/oSE\*100 (oSOL−sSOL)/oSOL

7

4

4

2

2

1

1

Combination scores

Derived index not reported Atypical index (described below)

11

5

0 10 20 30 40 50

Number of studies

Figure 19: Derived indices used for operationalising sleep discrepancy

Overall, the sleep variables TST, SOL, and WASO represented the substantial majority of derived indices. Arithmetic difference scores were the most common derived index and with these objective sleep was sub- tracted from self-report sleep considerably more often than vice-versa. By contrast, ratio scores did not differ

in directionality, and all that were recorded featured self-report sleep as the numerator and objective sleep as the denominator. Absolute differences are unique amongst derived indices for operationalising negative sleep discrepancy as equal to positive sleep discrepancy. With the relatively few absolute difference scores noted here it appears that the literature has mostly conceived of sleep discrepancy as a directional concept. All the combination scores identified followed the general format of an arithmetic difference score divided by a component of the difference.

A handful of more atypical derived scores were identified. Jackowska et al. (2011) created a sleep quality discrepancy index by subtracting a z-transformed self-report sleep quality rating from z-transformed objective SE. Kay et al. (2013) derived a nightly variability index for sSOL–oSOL and sWASO–oWASO by dividing intra-individual standard deviations by the sample-wise standard deviation for each variable. Mendelson et al. (1986) divided self-report sleep following experimental awakenings by objective sleep following experimental awakenings. Winer et al. (2021) derived a difference score from subtracting composite scores composed of the average of z scores of TST, SE, and sleep fragmentation (number of awakenings/SPT\*100) from z-transformed PSQI total scores.

### Other methods for operationalising sleep discrepancy

A number of other ways to characterise the relationship of sleep discrepancy with other variables of interest were identified and are depicted in Figure [20](#_bookmark20) below. Some studies operationalised sleep discrepancy using an interaction term within an ANOVA or other linear model such that the other variable(s) of interest was/were instantiated as the moderator of the relationship between self-report and objective sleep. Others used percentage agreement for sleep or other classification performance metrics in subsequent statistical analyses with other variables. Differences between correlations amongst self-report and objective sleep between groups were also tested with bootstrapped confidence intervals Jackson et al. (2020), or the Fisher transformation (De Francesco et al., 2021). Some operationalised sleep discrepancy with the Sleep Fragment Perception Index (SFPI), an index that exploits the fact that longer sleep fragments are more likely to be identified as sleep by individuals than shorter fragments (Hermans, Van Gilst, et al., 2020). The SPFI is a parameter modelled to assume the shortest length of objective sleep that is perceived as subjective sleep. For the SFPI, a higher value corresponds to a longer sleep fragment necessary for subjective awareness of sleep and hence greater sleep discrepancy.

Interaction Classification performance in statistical analysis

7

10

3

4

Method

Differences between correlations

Modelled parameter

0.0 2.5 5.0 7.5 10.0 12.5

Number of studies

Figure 20: Other methods for operationalising sleep discrepancy

## Miscellaneous methodological features

Lastly, we recorded some other methodological features of studies that appeared pertinent to the study of sleep discrepancy. Eleven studies investigated sleep discrepancy during, as a predictor of response to, or as an outcome of, cognitive behaviour therapy for insomnia (CBT-I). Fifteen studies used an experimental awakening paradigm where participants were monitored in-lab and woken by sound probes or technician interventions. A total of 15 studies were conducted with the aim of validating or assessing a particular sleep instrument.

# Discussion

This study reviewed ways of measuring, conceptualising, and analysing sleep discrepancy. Studies varied considerably across the broad range of recorded methodological characteristics and the number of records identified indicated a vast literature. At the level of measurement, objective sleep mostly consisted of polysomnography and actigraphy, whilst self-report sleep spanned a range of questionnaires and diaries of varying response formats. Within objective sleep measures, approaches varied according to setting, equip- ment, and processing of data. Sleep time-related metrics (e.g., TST, SOL, WASO) preponderated in the identified studies, with a small minority measuring direct sleep-wake agreement and a handful of studies mea- suring other sleep-related features or behaviours. Sleep quality was also investigated by a small number of studies. Definitions for sleep variables themselves did vary across studies although mainly on the self-report side and principally for the variables TST, WASO, and TIB, although objective SOL varied considerably. At the level of data processing and analysis, a range of strategies were employed to accommodate repeated measurements but for many studies, too, there was a single instance of recording. Direct comparisons were commonly made between self-report and objective sleep and these spanned a number of statistical approaches. Many studies went further than comparing self-report and objective sleep directly and attempted to inves- tigate the relationship between sleep discrepancy and other variables. This was achieved most often with derived indices (e.g., self-report TST–objective TST), although other strategies were also used. Our findings are discussed below with recommendations for further research where relevant.

## Methodological heterogeneity poses a problem for sleep discrepancy re- search

In measuring the discrepancy between two concepts, the discrepancy—or variability—within each concept itself is an important consideration. This is because in any single instance, the discrepancy being measured can be accounted for partially or completely by the variation within each concept. Our results indicate that self-report sleep or objective sleep are not monolithic entities but variegated in ways that may be important. Take, for example, the simplest methodological distinction in objective sleep measurement: polysomnography versus actigraphy. In comparison with PSG, actigraphy generally overestimates sleep and underestimates wake time, and can have trouble distinguishing sleep from quiescent periods of wakefulness (Marino et al., 2013). These trends have been observed to be greater for samples experiencing chronic medical or psychiatric conditions (Conley et al., 2019). Tryon (2004) has emphasised that these differences between polysomnography and actigraphy are systematic, rather than random, and that each validly measure different aspects of sleep.

This issue continues through finer methodological distinctions. For example, within actigraphy, estimation of sleep can vary substantially across the various scoring algorithms identified in this review. There is ample evidence indicating that the concordance of actigraphy to PSG by algorithm can vary according to the sample in question (Gao et al., 2022; Haghayegh et al., 2019; Quante et al., 2018; Souza et al., 2003) and algorithm performance can even vary based on the actigraph device used (Kripke et al., 2010). A further example can be represented by the sheer range of sleep variables available to operationalise sleep discrepancy. Discrepancy within each variable is likely to have a distinct theoretical meaning. For example, Castelnovo et al. (2019) noted that little overlap was found between individuals that misperceive TST and misperceive SOL. Important distinctions continue even within sleep variables themselves. We identified a range of self- report TST definitions, with the most common being direct queries (e.g., “how many hours did you sleep last night?”) and calculated parameters (e.g., TST = TIB–SOL–WASO–TWAK). Alameddine et al. (2015) compared these two definitions and found that calculated estimates tended to exceed those from direct queries. TST discrepancy was overall negative across their sample for those with and without insomnia and so it is possible that indirect queries produce self-report TST that is closer to objective estimates.

For each of these examples, there are differences in sleep discrepancy across methodological approaches that evidence indicates is likely to be systematic. To the extent to which these systematic differences map on to known conceptual differences, distinct kinds of sleep discrepancy must be assumed. If differences to do not map conceptual differences, methodological choices are arbitrary and introduce undue uncertainty into inferences (see, Hoffmann et al., 2021). This can be a significant problem. For studies investigating the rela-

tionship between sleep discrepancy and another construct, the variance accounted for by the span of possible approaches may well exceed that of the effect for which the researchers are looking. For studies describing sleep discrepancy within a population, findings may not generalise beyond the particular combination of methodological choices that were made in the study.

Addressing this issue may take a number of approaches. A stronger research focus on methods would be helpful overall, with studies such as Alameddine et al. (2015) having the potential to further demonstrate the effect of deceptively small changes in methodology. A more formal large-scale approach could involve the *multiverse analysis* of Steegen et al. (2016), systematically analysing across a variety of data sets resulting from different but justifiable methodological decisions. Specific tools such as structural equation modelling could be used to account for the variance represented by various methodological choices alone or in relation to other constructs (Bagozzi & Yi, 2012). Theoretical justification or another such rational account should also be provided for selection of sleep variables where possible, as many are likely to be conceptually distinct. A standardised approach to conducting and scoring actigraphy would also be tremendously beneficial, and serve to reduce the considerable methodological variance identified in this particular area.

## Methodological heterogeneity may influence the rate of false-positive find- ings

Methodological diversity may also have consequences on the rate of false-positives in the sleep discrepancy literature. The term *researcher degrees of freedom* has been used to refer to the range of possible decisions throughout the data collection and analysis process that can be exploited to yield tests that reach statistical significance (Simmons et al., 2011). As evidenced by this review, the amount of researcher degrees of freedom in sleep discrepancy research is considerable, particularly at the data analysis stage, and especially for sleep variable definition and selection. Any combination of the large number of sleep variables identified in this review may be chosen as an alternative analytic decisions during analysis. When the different possible definitions of each of these variables are also enumerated, the number of possible decisions seems endless. Note, this issue is not confined to the case of a researcher deliberately exploring analytical alternatives following a null result. In a problem referred to as the *garden of forking paths* (Gelman & Loken, 2013), any methodological decision made in response to an observed feature of the data increases the likelihood that findings will be misleading. An example of this would be selecting SE over TST for a subsequent analysis after observing that SE discrepancy best discriminated individuals with and without insomnia. Even though the eventual result is at this point unknown, the decision of sleep variable is contingent on the data, and ultimately, *p*-values will not reflect what would have happened had TST been chosen instead. For any study investigating the relationship of sleep discrepancy with other constructs, pre-registration of hypotheses and plans for data collection and analysis (Nosek et al., 2018) is likely to be helpful in minimising inflated Type I error through post-hoc methodological decisions.

## Definitions of objective sleep onset latency are multifarious and mostly arbitrary

Definitions of objective SOL vary considerably in the sleep discrepancy literature. Self-report sleep onset is more likely to coincide with the occurrence of the first sleep spindle, an EEG waveform associated with stage 2 sleep, than with the first incidence of stage 1 sleep (Bonnet & Moore, 1982). As such, R&K SOL is likely to have greater correspondence to self-report SOL than AASM SOL. This disparity would be expected to increase with greater sleep fragmentation in the early sleep period and substantial differences in AASM and R&K sleep discrepancy should be expected in samples with disrupted initial sleep. Stricter/longer SOL definitions including the Latency to Persistent Sleep (LPS) (Bianchi et al., 2012) and complex definitions from Means et al. (2003) and Lehrer et al. (2022) are expected to have the closest correspondence to self- report SOL, as research indicates 22-minutes of uninterrupted sleep is needed for healthy adults to perceive a bout of sleep during the beginning of the night (Hermans, Nano, et al., 2020).

Sleep onset is a continuous process for which it is diﬀicult to identify a clear start-point (Tryon, 2004). For example, with PSG scored by AASM criteria, 50% of a 30-second epoch is needed to exhibit sleep for the scoring of a first sleep stage. This means sleep latency is defined as the number of epochs preceding the

first uninterrupted ~16 seconds of an EEG depicting activity consistent with sleep. An individual could conceivably achieve this 16-second threshold within two minutes, wake up, and not return for another two hours (SOL = 2 minutes). Equally, an individual could spend a two hour period getting 14-second blocks of sleep before achieving a consolidated bout of sleep (SOL = 120 minutes). These are extreme examples, but they highlight the diﬀiculty with defining a single point of sleep onset. Of course, a line needs to be drawn somewhere, but the position of this line appears to be an arbitrary decision.

Saline et al. (2016) noted another problem although only for studies that investigate both TST and SOL concurrently. In the estimation of TST, individuals may attempt to judge the length of time between their subjective sleep onset and final wake time—anchoring their TST estimate to their SOL estimate. In measuring TST and SOL discrepancy, SOL discrepancy is thus being tested for twice: once in SOL and again implicitly in TST. Their solution to this problem was to obtain independent measurements by estimating the amount of objective sleep measured during the subjective sleep latency period (sleep during subjective latency; SDSL) and the amount of objective sleep measured following the subjective sleep latency period (latency adjusted total sleep time; LA-TST).

In view of these issues, three options are recommended in the context of sleep discrepancy research:

1. Proceed with defining objective SOL using latency to persistent sleep (LPS)—the first 20 consecutive epochs of sleep. Due to the considerable time it takes to perceive a bout of sleep and the rarity and limited magnitude of SOL underestimation (Hermans, Nano, et al., 2020; Saline et al., 2016) it makes sense to use a longer criterion than a shorter one. LPS also has the advantage of being simpler than many of the alternatives we identified.
2. Use SDSL for the reasons described in the previous paragraph. It should be noted, however, positive discrepancy (i.e., SOL underestimation) is not measurable with this method.
3. Avoid SOL as a sleep variable and to model sleep perception parameters during the sleep onset period according to Hermans et al. (2020).

Options two and three have the added advantage of operationalising sleep discrepancy without the use of derived scores—the problems with which are discussed briefly in a following paragraph.

## Sleep discrepancy is mostly restricted to sleep states or sleep time and varies in its conceptual distance to sleep misperception

To map the boundaries of the concept of sleep discrepancy, we included any studies comparing objective sleep with an equivalent measure of self-report sleep. From the very few studies identified investigating sleep patterns or other sleep-related behaviours it appears that sleep discrepancy is mostly restricted to discordance in sleep states (e.g., wakefulness versus sleep) or discordance in sleep time parameters (e.g., total sleep time). It may be helpful to consider sleep discrepancy, as so defined, in relationship to sleep misperception. These two terms have been used interchangeable in the past and the problems with doing this have been noted by a number of authors (Moul et al., 2004; Tryon, 2004). Stated simply, sleep is a complex process for which there no one perfectly valid measure, and using the term *sleep misperception* brings a status to objective measures of sleep that may not be warranted. For example, sleep-like EEG activity can occur during waking consciousness in a phenomenon known as local sleep (Krueger et al., 2019), and other dissociations between the EEG and sleep-related physiological processes have been observed under some conditions (Krueger et al., 2013). Moreover, conventional sleep scoring is but one way of classifying EEG data and subtler systems exist, including the cyclic alternative pattern (Parrino et al., 2012).

Whilst it may not be possible to directly measure sleep misperception for these reasons, sleep discrepancy can be closer or further to sleep misperception conceptually depending on its operational definition. Closest are studies measuring sleep-wake agreement or classification using EEG under laboratory conditions. In a case where a participant who, being asleep for five minutes, is woken by a technician and reports complete wakefulness for the preceding period, only the fallibility of objective recording can account for a conceptual distinction between sleep discrepancy and true sleep-state misperception. This fundamental sleep discrepancy represented by direct sleep-wake agreement can be contrasted with sleep discrepancy represented by sleep time variables (e.g., TST, SOL). Moving from sleep-wake agreement to sleep time variables introduces

additional factors that may account for the incongruence between self-report and objective sleep and hence provides a broader definition of sleep discrepancy. On the objective side, PSG potentially introduces artefact from transient (e.g., <15 second) awakenings (Smith & Trinder, 2000) and the arbitrary nature of SOL definitions (see section [5.3](#_bookmark21)). Actigraphy introduces the potential for immobile wake to be scored as sleep (Paquet et al., 2007; Souza et al., 2003) and variance contributed by methodological factors such as choices in scoring algorithms. On the self-report side, sleep diaries and questionnaires introduce memory or reporting biases (Clegg-Kraynok et al., 2023) as potential factors contributing to sleep discrepancy. See Harvey et al. (2012) for a discussion of these factors in the context of insomnia.

In the present review, we reported a key distinction between *habitual* and *episodic* measures of self-report sleep. Moving from episodic to habitual measures broadens the concept of sleep discrepancy yet further. A more global sleep discrepancy may be represented by comparisons of habitual self-report sleep with ag- gregated objective sleep (e.g., mean sleep variables values across 14 nights of actigraphy), the underlying processes for which are likely different to those of individual nights. Where habitual self-report sleep is compared to objective estimates spanning one to a few nights, intra-individual variation in sleep patterns is introduced to sleep discrepancy. In other words, some component of the difference between objective and self-report sleep can be accounted for by the difference between habitual sleep and the circumstances of testing—which may be substantial. If the objective measure is PSG, effects of the laboratory/testing environment (i.e., the first night effect Agnew et al., 1966; Newell et al., 2012) are additionally introduced. These forms of sleep discrepancy are illustrated in the matrix provided in Figure [21](#_bookmark22).

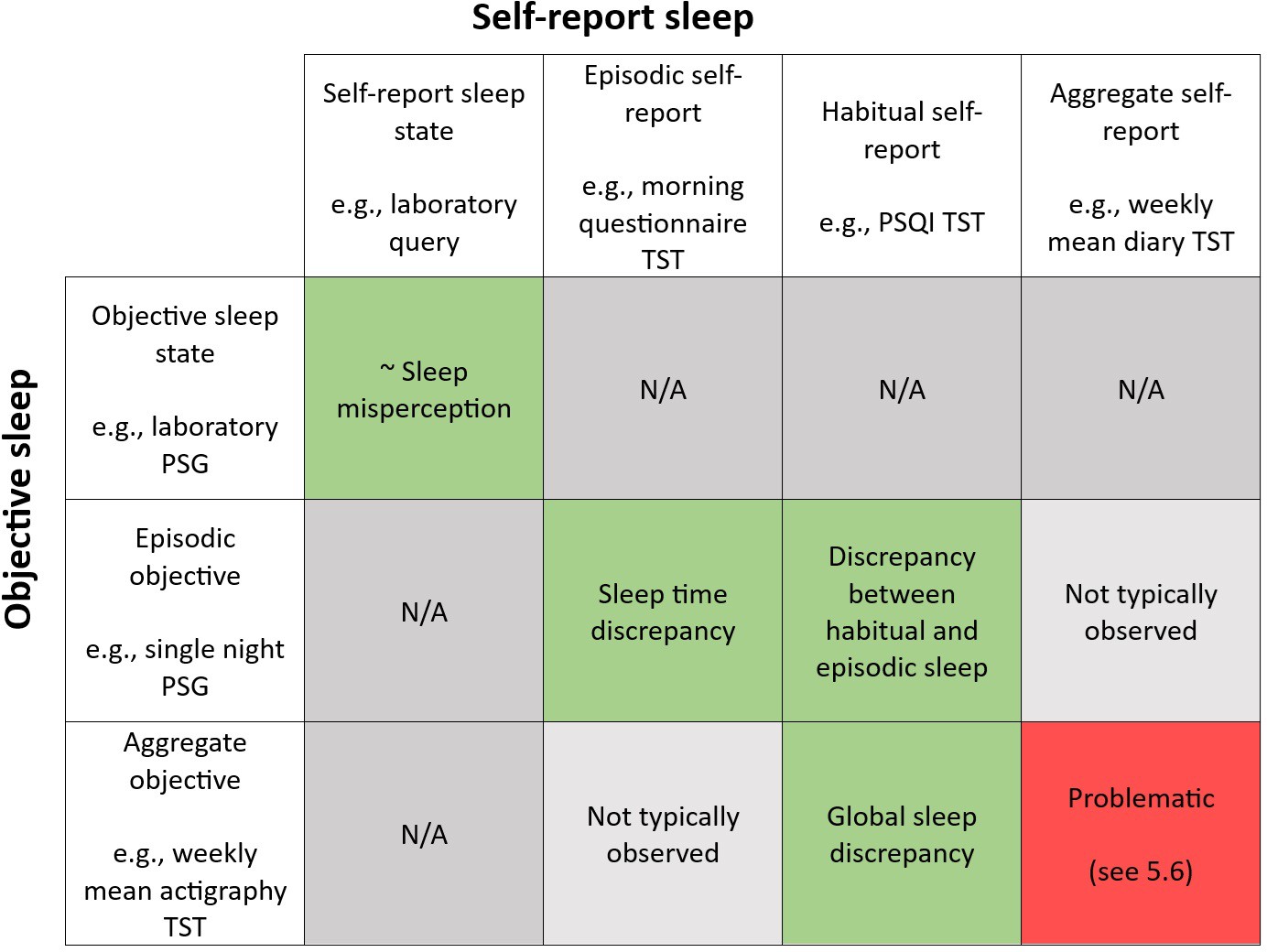


Figure 21: Sleep discrepancy matrix

*Note.* Conceptual proximity of sleep discrepancy to true sleep sate misperception decreases moving down and

across the figure. Problems using aggregate measures of both self-report and objective sleep are described in more detail in section [5.6](#_bookmark23)

## Derived indices are common and the use of these as an operational measure of sleep discrepancy is problematic

Derived variables, including difference scores and ratio scores, are overwhelmingly the most common way of operationalising sleep discrepancy to investigate its relationship with other variables. The use of derived variables for such a purpose is associated with a range of conceptual and methodological problems (Cronbach & Furby, 1970; Edwards, 2002; Kronmal, 1993) that are severe enough to warrant discontinuing their use in sleep discrepancy research. Stated briefly, in a relationship with another variable, the effect of each component of a derived index (e.g., a difference score representing the subtraction of self-report from objective TST) is confounded such that it is not possible to determine whether self-report sleep, objective sleep, or some combination of the two are driving the relationship (Edwards, 2002). Moreover, derived scores impose inappropriate constraints on relationships between other variables that are often not entailed by, or else contradictory to, stated hypotheses (Edwards, 2002). A large range of derived variables were identified by this review, none of which escape the problems described by the aforementioned authors. Fortunately, a number of alternative strategies for characterising relationships between sleep discrepancy and other constructs are available. Such methods identified in this review included using classification performance metrics within conventional statistical analyses, representing sleep discrepancy with moderation/interaction effects, and modelling sleep discrepancy parameters mathematically.

## Averaging sleep variables across multiple nights is a common practice and can cause problems

In the studies identified in this review, the most common way of handling repeated measurements of sleep variables was by averaging across multiple instances of recording. This technique is problematic when applied to concurrent episodic (i.e., nightly) measurements of self-report and objective sleep as it relies on the assumption that patterns of sleep over/underestimation are consistent across nights. Extreme positive and negative sleep discrepancy occurring alternately on successive nights could result in averages denoting negligible discrepancy. This may be a realistic concern for research in sleep discrepancy and insomnia, for example. Although most individuals with insomnia tend to underestimate sleep, high inter-night variability is observed (Herbert et al., 2017) and some individuals will overestimate sleep (Lindert et al., 2020; Trajanovic et al., 2007). An exception to this problem exists in the case of comparing aggregated objective sleep against a habitual measure of self-report sleep, such as the PSQI. Here, using means or medians to determine habitual measures of objective sleep is necessary to define sleep discrepancy at the habitual, rather than the episodic level. In other cases, linear mixed models, generalised estimating equations, and structural equation models were methods identified in this review that can avoid problems with averaging across repeated measures.

## Correlations have sometimes been used inappropriately as a measure of concordance

Despite being the most common approach to comparing self-report and objective sleep measures, Pearson or Spearman correlations are broadly inappropriate for the characterisation of agreement or discrepancy. Correlation is strictly a measure of association between two variables and is insensitive to systematic error between measures (Liu et al., 2016). For example, the same correlation coeﬀicient may equally describe a sample where self-report and objective estimates of sleep tend to be equal as one where (i), objective estimates tend to exceed self-report estimates by a given constant (e.g., two hours) or (ii), the value of objective sleep varies proportional to the level of self-report sleep. Measures of agreement including Bland-Altman analyses, intra-class correlation, and Lin’s concordance coeﬀicient were also used by a large number of studies and are preferable for the measurement of discrepancy in equivalent parameters.

## Sleep quality discrepancy is conceptually unclear

Sleep quality discrepancy was measured by a small number of studies in this review, according to varying strategies. Sleep quality discrepancy is a diﬀicult topic for two reasons. First, there is no consensus approach to operationalising sleep quality. A recent review of methods for measuring sleep quality identified an immense range in strategies, especially for objective measures (Mendonça et al., 2019). Second, there are no clear self-report analogues for objective measures of sleep quality, or vice-versa. An individual is unable to directly estimate their number of EEG arousals, quantity or proportion of N3 sleep, or other features of sleep macro or microstructure unavailable to consciousness. Equally, it is not clear how to compare a sleep quality rating judgement (e.g., on a Likert scale) with objective measures (see Krystal & Edinger, 2008). Overall, investigating the relationships of sleep quality discrepancy to other variables is unlikely to be profitable until the conceptual status of self-report and objective sleep quality is clearer.

## Sleep diaries should not be used to define rest intervals in sleep discrepancy research

Sleep diaries were the most commonly identified method of rest interval definition in this review. Sleep diaries were classified by this review as a self-report measure of sleep. By using sleep diaries to define actigraphic rest intervals, self-report sleep is being used to partially define an objective sleep measure. In this case, the measured discrepancy between the two forms of sleep measurement will not be an accurate representation of their actual incongruence. The high frequency at which sleep diaries are back-filled or misreported (Clegg-Kraynok et al., 2023) highlights the significance of this issue. We noted that a single study in the present review addressed this problem directly. Krahn et al. (1997) ensured that manual scorers of the rest intervals for their actigraphy data were blinded to the sleep diary. It may be helpful for further research that alternatives such as these are sought for defining rest interval periods.

## The scope of sleep discrepancy research is likely to have been underesti- mated

The scope of the literature on sleep discrepancy has been considerably underestimated to date. We intended to identify a broad range of studies in this review that may have captured the concept of sleep discrepancy without necessarily referring to this or related terms. A search across full texts of all studies included in this review returned 63 records making explicit mention of “sleep” and “discrepancy”, leaving 185 that would have otherwise been unidentifiable through simple keyword searching of this concept. It is likely that existing sleep discrepancy research across domains may be excessively siloed into respective research areas. Looking at the clinical populations encompassed in this review, there appear to be small but distinguishable sleep discrepancy research programmes in post-traumatic stress disorder, bipolar disorder, pregnancy, traumatic brain injury, and fibromyalgia, to name just a few. Whilst sleep discrepancy is best understood in the context of insomnia, it is possible similar processes underlie the presence of sleep discrepancy in these groups. For example, the role of sleep disturbance as a transdiagnostic factor across psychiatric disorders has been emphasised (Harvey et al., 2011) and a mechanistic role for sleep misperception has been suggested for disorders outside of insomnia (Richardson et al., 2016).

## Strengths and limitations

This study represents the largest systematic approach to investigating methodology in the area of sleep discrepancy research. We reported a broad range of methodological features across a large number of studies and provided meaningful syntheses of research methods in a diverse field. Two major changes were made to our own methods during the screening process and following registration of the scoping review protocol that may be viewed as limitations. These changes were both made in response to the unanticipated number of records returned following title and abstract screening and in view of limited resources available for charting and synthesis. First, grey literature was removed from inclusion criteria. Although the issues and recommendations discussed in this paper were limited to published research, our findings remain broadly applicable and no syntheses of empirical findings have been made that could be influenced by publication

bias. Second, reference lists were not screened for additional studies and the extent to which this review may be considered an exhaustive representation of the literature may be reduced as a result.

## Practice points

1. Sleep discrepancy has been investigated throughout a broad range of clinical populations outside of insomnia
2. Many sleep discrepancy studies involve at least one significant methodological problem that may threaten the validity of findings
3. Available alternatives to operationalising SOL should be employed over traditional approaches
4. Rest intervals should be defined without the use of sleep diaries if actigraphy is to be used to measure sleep discrepancy

## Research Agenda

1. Further research is necessary to determine where methodological differences in sleep discrepancy ap- proaches indicate meaningful conceptual differences
2. The impact of varying justified approaches to measuring and operationalising sleep discrepancy should be assessed
3. Integrated and standardised approaches to conducting actigraphy would benefit sleep discrepancy re- search by reducing methodological heterogeneity
4. Open science practices including pre-registration and research transparency have the potential to im- prove sleep discrepancy research

## Summary

Methods for investigating sleep discrepancy have varied considerably in the literature across the areas of study design, measurement, data processing, and data analysis. Many of these varied approaches have substantial effects on what sleep discrepancy means as a concept and sometimes are associated with methodological problems that may not be immediately clear. Sleep discrepancy research holds promise for advancing under- standing of sleep, its disorders such as insomnia, and mechanisms at play in psychiatric and other disorders. Clear concepts and appropriate methodology is essential to ensure that work in this area remains a progres- sive science. Measuring discrepancy or congruence is often a deceptively complex undertaking and we hope that this scoping review will prove helpful and informative to those interested in designing or interpreting sleep discrepancy studies.

# Data availability statement

All code and data underlying this article are available from github: [https://github.com/tfwalton/sleep-](https://github.com/tfwalton/sleep-discrepancy-review) [discrepancy-review](https://github.com/tfwalton/sleep-discrepancy-review).

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# Declaration of competing interest

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

# Appendices

## Search strategies

Search strategies for databases searched using the Ovid system are available in Table [2](#_bookmark24).

Table 2: Search strategy for Ovid databases

Step Terms and operators Records

**Embase**

1. sleep discrepancy or paradoxical insomnia or subjective insomnia or (sleep adj2 misperception).mp
2. ((self report\* or diary or subjective\*) and (objective\* or actigraph\* or polysomnograph\* or polygraph\*)).mp.

488

193243

1. (exp polysomnography/ or exp actimetry/) and exp self report/ 1676
2. (sleep\* and (”over estimat\*” or ”over report\*” or ”under estimat\*” or ”under report\*” or overestimat\* or overreport\* or underestimat\* or underreport\* or discrepan\* or concordan\* or agreement or disagreement or discordan\* or congruen\* or incongruen\*)).mp.

|  |  |  |
| --- | --- | --- |
| 5 | 2 or 3 | 193302 |
| 6 | 4 and 5 | 1234 |
| 7 | 1 or 6 | 1569 |

9362

**PsycINFO**

1. sleep discrepancy or paradoxical insomnia or subjective insomnia or (sleep adj2 misperception).mp
2. ((self report\* or diary or subjective\*) and (objective\* or actigraph\* or polysomnograph\* or polygraph\*)).mp.

175

57592

1. (exp polysomnography/ or exp actigraphy/) and exp self report/ 59
2. (sleep\* and (”over estimat\*” or ”over report\*” or ”under estimat\*” or ”under report\*” or overestimat\* or overreport\* or underestimat\* or underreport\* or discrepan\* or concordan\* or agreement or disagreement or discordan\* or congruen\* or incongruen\*)).mp.

|  |  |  |
| --- | --- | --- |
| 5 | 2 or 3 | 57592 |
| 6 | 4 and 5 | 346 |
| 7 | 1 or 6 | 471 |

2112

**Medline**

1. sleep discrepancy or paradoxical insomnia or subjective insomnia or (sleep adj2 misperception).mp
2. ((self report\* or diary or subjective\*) and (objective\* or actigraph\* or polysomnograph\* or polygraph\*)).mp.

260

139088

1. (exp polysomnography/ or exp actigraphy/) and exp self report/ 561
2. (sleep\* and (”over estimat\*” or ”over report\*” or ”under estimat\*” or ”under report\*” or overestimat\* or overreport\* or underestimat\* or underreport\* or discrepan\* or concordan\* or agreement or disagreement or discordan\* or congruen\* or incongruen\*)).mp.

|  |  |  |
| --- | --- | --- |
| 5 | 2 or 3 | 139088 |
| 6 | 4 and 5 | 692 |
| 7 | 1 or 6 | 875 |

5280

Search strategies for other databases are listed in Table [3](#_bookmark25).

Table 3: Search strategy for other databases

Database Terms and operators Records

Pubmed (”sleep discrepancy” OR ”paradoxical insomnia” OR ”subjective insomnia”) OR (sleep AND misperception) OR ((”self report\*” or diary or subjective\*) AND (objective\* or actigraph\* or polysomnograph\* or polygraph\*)) OR ((”Polysomnography/methods”[MAJR] OR ”Actigraphy/methods”[MAJR]) AND ”Self Report”[MeSH]) AND (sleep\* AND (”over estimat\*” OR ”over report\*” OR ”under estimat\*” OR ”under report\*” OR overestimat\* OR overreport\* OR underestimat\* OR underreport\* OR discrepan\* OR concordan\* OR agreement OR disagreement OR discordan\* OR congruen\* OR incongruen\*))

CINAHL (”sleep discrepancy” OR ”paradoxical insomnia” OR ”subjective insomnia”) OR (sleep AND misperception) OR ((”self report\*” or diary or subjective\*) AND (objective\* or actigraph\* or polysomnograph\* or polygraph\*)) AND (sleep\* AND (”over estimat\*” OR ”over report\*” OR ”under estimat\*” OR ”under report\*” OR overestimat\* OR overreport\* OR underestimat\* OR underreport\* OR discrepan\* OR concordan\* OR agreement OR disagreement OR discordan\* OR congruen\* OR incongruen\*))

Scopus TITLE-ABS-KEY ( ( ”sleep discrepancy” OR ”paradoxical insomnia” OR ”subjective insomnia” ) OR ( sleep AND misperception ) OR ( ( ”self report\*” OR diary OR subjective\* ) AND ( objective\* OR actigraph\* OR polysomnograph\* OR polygraph\*

) ) AND ( sleep\* AND ( ”over estimat\*” OR ”over report\*” OR ”under estimat\*” OR ”under report\*” OR overestimat\* OR overreport\* OR underestimat\* OR underreport\* OR discrepan\* OR concordan\* OR agreement OR disagreement OR discordan\* OR congruen\* OR incongruen\* ) ) )

Web of Science (”sleep discrepancy” OR ”paradoxical insomnia” OR ”subjective insomnia”) OR (sleep AND misperception) OR ((”self report\*” or diary or subjective\*) AND (objective\* or actigraph\* or polysomnograph\* or polygraph\*)) AND (sleep\* AND (”over estimat\*” OR ”over report\*” OR ”under estimat\*” OR ”under report\*” OR overestimat\* OR overreport\* OR underestimat\* OR underreport\* OR discrepan\* OR concordan\* OR agreement OR disagreement OR discordan\* OR congruen\* OR incongruen\*))

761

310

826

1288

Proquest Theses and Dissertations Global

noft((”sleep discrepancy” OR ”paradoxical insomnia” OR ”subjective insomnia”) OR 90

(sleep AND misperception) OR (((”self report\*” or diary or subjective\*) AND (objective\* or actigraph\* or polysomnograph\* or polygraph\*)) AND (sleep\* AND (”over estimat\*” OR ”over report\*” OR ”under estimat\*” OR ”under report\*” OR overestimat\* OR overreport\* OR underestimat\* OR underreport\* OR discrepan\* OR concordan\* OR agreement OR disagreement OR discordan\* OR congruen\* OR incongruen\*))))

## List of deviations from protocol

The following are a list of deviations from the scoping review protocol registered on the Open Science Framework (doi: 10.17605/OSF.IO/BCJNQ).

1. The term actimetry in Medline and PSYCinfo searches was changed to actigraphy
2. The scoping review protocol listed an incorrect number of duplicates records following searches
3. All records that were not peer reviewed journal articles were excluded at the full-text screening stage in the final review
4. Other items were added to the exclusion criteria at the full-text screening stage including:
   * study measured informant-report rather than strictly self-report sleep
   * study did not include statistical comparison of self-report and objective sleep (e.g., numerical compar- isons only, single-case design)
5. Reference lists were not searched for additional citations as planned in the protocol

## PRISMA-ScR checklist

A PRISMA-ScR checklist is available below with section links to the corresponding checklist item.

Table 4: Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist.

Section Item PRISMA-ScR Checklist Item Location reported

**Title**

Title 1 Identify the report as a scoping review. 1

**Abstract**

Structured summary

**Introduction**

2 Provide a structure summary that includes (as applicable): background, 1

objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.

Rationale 3 Describe the rationale for the review in the context of what is already 2

known. Explain why the review questions/ objectives lend themselves to a scoping review approach

Objectives 4 Provide an explicit statement of the questions and objectives being 2

addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualise the review questions and/or objectives.

**Methods**

Protocol and registrations

Eligibility criteria

Information sources

1. Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.
2. Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.
3. Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.

3.1

3.2

3.4

Search 8 Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.

3.1

Selection of sources of evidence

Data charting process

1. State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.
2. Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.

3.5

3.6

Data items 11 List and define all variables for which data were sought and any

assumptions and simplifications made

3.7

Critical appraisal of individual sources of evidence

Synthesis of results

**Results**

Selection of sources of evidence

Characteristics of sources of evidence

Critical appraisal within sources of evidence

1. If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).
2. Describe the methods of handling and summarizing the data that were charted
3. Give numbers of sources of evidence screen, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.
4. For each source of evidence, present characteristics for which data were charted and provide the citations.
5. If done, present data on critical appraisal of included sources of evidence (see item 12).

Formal quality assessment was not conducted

3.8

4

Formal quality assessment was not conducted

Results of individual sources of evidence

Synthesis of results

**Discussion**

Summary of evidence

1. For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.
2. Summarize and/or present the charting results as they relate to the review questions and objectives.
3. Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups

4.2

4.2

5

Limitations 20 Discuss the limitations of the scoping review process. 5.11

Conclusions 21 Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.

5.12

**Funding**

Funding 22 Describe sources of funding for the included sources of evidence, as well as 9 sources of funding for the scoping review. Describe the role of the funders

of the scoping review.

## 11.4 Additional tables

Full descriptions of study characteristics are available in Table [5](#_bookmark27).

Table 5: Characteristics of included studies

|  |  |  |  |
| --- | --- | --- | --- |
| Study | Country of origin | Sample characteristics | Sample size |
| Ahn et al. (2021) | Korea | Patients >55 years with insomnia disorders | 33 |
| Al Lawati et al. (2021) | Oman | Healthy Omani nationals | 321 |
| Alameddine et al. (2015) | USA | Participants referred to a sleep centre for PSG | 879 |
| Ansok et al. (2020) | USA | Patients with rotator cuff tears | 18 |
| Argyropoulos et al. | United | Outpatients with moderate to severe depression, without | 40 |
| (2003) | Kingdom | psychotic features, in an RCT of two antidepressants |  |
| Aritake-Okada et al. | Japan | Healthy males | 22 |
| (2010)  Arora et al. (2013) | United | Adolescents aged 11-13 | 255 |

Kingdom

Auger et al. (2013) USA Patients referred to an academic sleep centre 84

Baek et al. (2020) Korea Shiftwork nurses 94

Baillet et al. (2016) France Older adults with no sleep disorders, sleep medications, or 45

depressive symptomatology

Baker et al. (1999) South Africa Healthy young subjects 20

Barbosa et al. (2017) Brazil Visually impaired individuals and participants without visual 77

impairment

|  |  |  |  |
| --- | --- | --- | --- |
| Bastien et al. (2013) | Canada | Individuals with chronic psychophysiological insomnia, | 88 |
| Bean et al. (2021) | New | paradoxical insomnia and good sleepers Chronic pain patients | 47 |
| Bensen-Boakes et al. | Zealand Australia | Participants with comborbid insomnia and OSA | 145 |
| (2022) |  |  |  |
| Bian et al. (2016) | China | Inpatients with schizophrenia | 148 |
| Bianchi et al. (2012) | USA | Healthy subjects undergoing in-lab sleep experiment | 44 |
| Bianchi et al. (2013) | USA | Patients referred to a sleep centre | 312 |
| Billings (2020) | USA | Firefighters | 24 |
| Bonnet & Moore (1982) | USA | Young adults | 12 |
| Broomfield & Espie | United | Individuals complaining of sleep-onset insomnia | 34 |
| (2003)  Brychta et al. (2019) | Kingdom Iceland | 15-year, then 17-year old students of the same cohort | 144 |
| Caia et al. (2018) | Australia | Professional rugby league athletes | 63 |
| Campanini et al. (2017) | Brazil | School teachers | 163 |
| Carter et al. (2020) | USA | Collegiate athletes | 121 |
| Castelnovo et al. (2021) | Switzerland | Patients with insomnia | 249 |
| Castillo et al. (2014) | USA | Patients referred to a sleep centre for PSG | 405 |
| Cederberg et al. (2022) | USA | Patients with multiple sclerosis | 49 |
| Chan et al. (2018) | USA | Individuals with fibromyalgia and Insomnia | 223 |
| Chan et al. (2021) | USA | Community dwelling older adults with insomnia | 62 |
| Chen et al. (2015) | Taiwan | Individuals with osteoarthritis | 30 |
| Chervin & Guilleminault (1996)  Cho et al. (2022) | USA  Korea | Patients referred to a sleep centre for an MSLT for suspected excessive daytime somnolence  Participants from the sleep heart health study | 147  2540 |
| Choi et al. (2016) | Korea | Patients referred to a sleep centre for PSG in addition to | 420 |

healthy volunteers

Chou et al. (2020) USA Cognitively normal and mildly impaired older adults 293

Chung et al. (2020) Korea Outpatients with schizophrenia 66

Combertaldi & Rasch (2020)

|  |  |  |  |
| --- | --- | --- | --- |
| Conroy et al. (2006) | USA | Individuals experiencing insomnia in recovery from alcohol | 21 |
|  |  | dependence |  |
| Creti et al. (2010) | Canada | Participants with chronic fatigue syndrome | 49 |
| Crönlein et al. (2019) | Germany | Patients receiving CBT-I for insomnia | 92 |

Switzerland Young healthy students 24

Currie et al. (2004) Canada Individuals experiencing insomnia in recovery from alcohol 56

dependence

Curtis et al. (2019) USA Participants with fibromyalgia and insomnia 199

D’Aoust et al. (2015) USA Informal caregivers of persons with dementia 53

Dautovich et al. (2008) USA Older adults who nap habitually 100

De Francesco et al. (2021)

United Kingdom

People with HIV and people without HIV matched on demographic variables

461

De Jaeger et al. (2019) Belgium Failed back surgery syndrome (FBSS) patients treated with 19

spinal cord stimulation

Dean et al. (2019) USA Adults with inoperable non-small cell lung cancer 26

Devine et al. (2020) USA Army Reserve Oﬀicers’ Training Corp Cadets 286

Dietch & Taylor (2021) USA Representative community-based normative sample 80

Dinapoli et al. (2017) Italy Older adults with mild cognitive impairment and subsyndromal 59

depression

Dittoni et al. (2013) Italy Chronic primary insomnia patients 66

Dorrian et al. (2012) Australia Commercial passenger airline pilots 306

Dorsey & Bootzin (1997) USA Undergraduate students 31

Downey & Bonnet (1992) USA Subjective insomniacs 10

Duarte et al. (2020) Brazil Patients undergoing PSG for suspected sleep-disordered breathing

727

Duarte et al. (2022) Brazil Individuals with sleep disorders and contrls 2004

Dunican et al. (2017) Australia Judo athletes 23

Dzierzewski et al. (2019) USA Older adults with insomnia 159

Edinger & Fins (1995) USA Outpatients with insomnia presenting to a sleep disorders centre 173

Espie et al. (1989) United Kingdom

Individuals with insomnia 20

Etain et al. (2021) France Adults with bipolar disorder and healthy controls 154

Facco et al. (2018) USA Nulliparous women enrolled in the first trimester of pregnancy 752

Feige et al. (2008) Germany Individuals with paradoxical insomnia and good sleeper controls 200

Feige et al. (2021) Germany Insomnia patients and good sleeper controls 100

Feng & Svetnik (2018) United

Kingdom

Primary insomnia patients n/a

Fernandez-Mendoza et al. USA Insomniacs and controls 866

(2011)

Finan et al. (2020) USA Participants with opioid use disorder 55

Franklin & Svanborg (2000)

Sweden Individuals referred to sleep center for suspected OSA 100

Friedmann et al. (2022) Germany Women with PTSD after childhood abuse, mentally healthy

women with a history of child abuse, and nontraumatised mentally healthy women

184

Gaina et al. (2004) Japan Healthy junior high school children 42

Ghadami et al. (2015) Iran War veterans diagnosed with chronic PTSD 32

Gibson et al. (2022) Australia Australian army recruits 59

Girschik et al. (2012) Australia Women recruited from the community 56

Gonzalez et al. (2013) USA Individuals with bipolar type I 39

Gooneratne et al. (2011) USA Older adults with and without insomnia complaint 200

Goudman et al. (2018) Belgium Patients with failed back surgery syndrome treated with spinal 39

chord stimulation

Goulart et al. (2014) Brazil Healthy males with normal sleep randomised to three 31

experimental groups

Guedes et al. (2016) Brazil Adolescents 37

Gökce et al. (2020) Germany Young adults in Munich 74

Hall et al. (2022) USA Women with PTSD secondary to interpersonal violence 45

Hanisch et al. (2011) USA Prostate cancer patients undergoing androgen therapy 60

He et al. (2021) China Adults participants subject to COVID-19 lockdown provisions in 70

China

|  |  |  |  |
| --- | --- | --- | --- |
| Heath et al. (2018) | Australia | Adolescents | 385 |
| Herbert et al. (2017) | United | Individuals with insomnia symptoms | 42 |
| Hermans et al. (2019) | Kingdom  Netherlands | Older adults with and without insomnia | 41 |

Hermans et al. (2020) Netherlands Insomnia patients and healthy controls 231

Hermans et al. (2020) Netherlands Participants with insomnia on a waitlist for CBT-I 31

Hermans et al. (2021) Netherlands Older adults involved in a double-blind crossover study with 46

zopiclone and placebo

Herring et al. (2013) USA Urban low-income pregnant women 80

Hita-Yañez et al. (2013) Spain Patients with MCI and healthy elderly 50

Hodges et al. (2017) USA Cocaine-dependent persons admitted to an inpatient research 43

facility

Hoogerhoud et al. (2015) Netherlands Patients receiving index or maintenance ECT for a depressive 12

episode

Hsiao et al. (2018) Taiwan Healthy young adults 36

Huang et al. (2012) China Primary insomnia patients and healthy controls 170

Hughes et al. (2018) USA Vulnerable older adults participating in a Veterans 59

Administration Adult Day Health Care (ADHC) program

Hur et al. (2020) Canada Patients with interstitial lung disease 111

Ihler et al. (2020) France, Norway

Individuals with bipolar disorder and healthy controls 196

Jackowska et al. (2011) United

Kingdom

Women working at University College London and neighbouring 179 institutions

Jackson et al. (2018) USA Adults enrolled in a large longitudinal study 1910

Jackson et al. (2019) USA African-American adults 821

Janků et al. (2020) Czech Republic

Insomnia patients 36

Jungquist et al. (2016) USA Community-dwelling adults 300

Kang et al. (2018) USA Individuals with major depressive disorder, individuals with 82

primary insomnia, and normal sleeping controls

Kaplan et al. (2012) USA Individuals with bipolar disorder and age and sex-matched 54

controls

Kaufmann et al. (2019) USA Individuals with bopolar disorder and healthy controls 85

Kawada (2008) Japan Healthy university students 76

Kay et al. (2013) USA Older adults with and without sleep complaint 103

Kay et al. (2015) USA Older adults with and without insomnia 114

Kay et al. (2017) USA Individuals with paradoxical insomnia and good sleeper controls 62

Keklund & Akerstedt (1997)

Sweden Individuals involved in a study of early morning work or a study 37 of sleep in a truck-berth

Kennedy et al. (2020) Ireland Patients with advanced chronic kidney disease or end-stage 54

kidney disease

Khou et al. (2018) USA Community dwelling older adults with and without mild 86

Alzheimers disease

King et al. (2017) USA Female undergraduates enrolled in an interior design programme 28 Kishikawa et al. (2021) Japan Outpatients with primary insomnia undergoing CBT-I 52

Kobayashi et al. (2012) USA Urban-residing African Americans with and without trauma

exposure and PTSD

Kolling et al. (2016) Germany German undergraduate and graduate physical education

students

Kong et al. (2011) China Children recruited from primary and secondary schools in Hong

King

103

72

133

Krahn et al. (1997) USA Psychiatric inpatients 30

Kreutz et al. (2021) Germany Breast cancer patients starting neoadjuvant chemotherapy 54

Krishnamurthy et al. (2018)

USA Bipolar disorder patients and healthy controls similar in age, 54

race, and sex

Kryger et al. (1991) Canada Patients with chronic insomnia 16

Krystal & Edinger (2010) USA Patients with primary insomnia with sleep maintenance 30

diﬀiculty evident in subjective sleep measures

Krystal et al. (2002) USA Individuals with subjective insomnia, objective insomnia and 50

normal controls

Kundu et al. India Individuals with chronic insomnia and obstructive sleep apnoea 32 Kung et al. (2015) Taiwan Taiwanese adults with major depression 30

Lan Chun Yang et al. (2021)

Canada Participants diagnosed with mTBI/concussion 37

Laranjeira et al. (2018) Brazil Individuals referred to a sleep centre 248

Lastella et al. (2018) Australia Well-trained male soccer players 12

Lauderdale et al. (2008) USA Young adults enrolled in the Coronary Artery Risk Development 647

in Young Adults study

Lecci et al. (2020) Switzerland Population-based sample 2092

Lecci et al. (2020) (study Switzerland Insomnia patients and healthy subjects 34

2)

Lee (2021) United

Kingdom

Adults aged 20 or above 8438

Lee et al. (2021) Korea Adults with insomnia 105

Lee et al. (2022) Korea Patients with OSA 707

Lehrer et al. (2022) USA Middle-aged community-dwelling women 323

Lewis (1969) United Kingdom

Healthy young men 8

Lipinska & Thomas (2017)

South Africa Women with PTSD, trauma exposure with no PTSD, and 60

healthy controls

Liu et al. (2019) China Healthy young adults 10

Liu et al. (2020) China Patients diagnosed with OSA 355

Locihova et al. (2020) Czech

Republic

Lockley et al. (1999) United Kingdom

Patients admitted to an intensive care unit of a hospital 20

Blind individuals 49

Lubas et al. (2022) USA Participants enrolled in a longitudinal study of survivors of

childhood cancer

477

Lund et al. (2013) USA Older adults with comorbid insomnia 60

Ma et al. (2021) USA Individuals with insomnia, insomnia & comorbid OSA, OSA

only, and normal sleep controls

Maes et al. (2014) Belgium Female patients diagnosed with primary insomnia and healthy female controls

638

28

Maich et al. (2018) Canada Individuals with insomnia and good sleeper controls 74

Majer et al. (2007) USA Individuals with chronic fatigue and non-fatigued controls 75

Manconi et al. (2010) Italy, USA Normal subjects 288

Manconi et al. (2010) (study 2)

Italy 159 patients with primary insomnia 159

Maric et al. (2019) Switzerland Healthy right-hand males 14

Martinez et al. (2010) Brazil Patients referred to a university-aﬀiliated sleep clinic for PSG 5764

Matousek et al. (2004) Czech

Republic

Patients with minor depression, complaining of insomnia 28

Mazza et al. (2020) France Children aged 8-9 years recruited from elementary schools 76

McCall & McCall (2012) USA Patients diagnosed with current major depressive episode and 54

chronic insomnia

McCall et al. (1995) USA Individuals undergoing PSG for suspected sleep apnoea 84

McIntyre et al. (2016) New Zealand

Healthy women late in third trimester 30

Means et al. (2003) USA Middle-aged and older individuals with insomnia and matched 101

normal sleepers

Mendelson (1998) USA Participants who complained of poor sleep 8

Mendelson et al. (1986) USA Individuals with insomnia and age and sex matched controls 20

Mercer et al. (2002) USA Individuals with insomnia and good sleepers 22

Meyer et al. (2018) United Kingdom

Outpatients with schizophrenia 14

Miner et al. (2022) USA Community-dwelling older adults 5835

Moore et al. (2015) USA 43 women with insomnia who had completed treatment for breast cancer

Most et al. (2012) Netherlands Older adults with early and late stage alzheimers disease or healthy controls

Mundt et al. (2016) USA Adults with insomnia and fibromyalgia randomised to CBT-I,

CBT for pain, or waitlist control

43

81

113

Nam et al. (2016) Korea Patients referred to a sleep clinic for evaluation of snoring/OSA 50 Narisawa et al. (2015) Japan Participants with subjective sleep diﬀiculty 50

Nazem et al. (2016) USA Male veterans with traumatic brain injury 19

Neu et al. (2007) Belgium Individuals with chronic fatigue and female controls 40

Nguyen-Michel et al. (2015)

France Older adults referred for insomnia complaints or suspected sleep apnoea

135

Normand et al. (2016) Canada Paradoxical insomnia, psychophysiological insomnia, good 70

sleepers

O’Brien et al. (2016) USA Treatment-seeking overwieght/obese participants 63

Okifuji & Hare (2011) USA Patients with fibromyalgia 75

Okun et al. (2021) USA Pregnant women 104

Orta et al. (2016) Chile Female primary caregivers of children with disabilities 175

Ouellet & Morin (2006) Canada Patients with mild to severe traumatic brain injury and healthy 28

good sleepers

Park et al. (2007) USA Postmenopausal women 384

Perlis et al. (1997) USA Female fibromyalgia patients 20

Perlis et al. (2001) USA Individuals with primary insomnia, insomnia secondary to 27

depression, and good sleeper controls

Pinto Jr et al. (2009) Brazil Individuals selected from a university sleep laboratory 199

Provencher et al. (2020) Canada Individuals with psychophysiological insomnia, paradoxical

insomnia, and good sleepers

Reess et al. (2010) Germany Patients with insomnia, sleep-related movement disorders

(SMD), hypersomnia, and parasomnia

67

159

Regestein et al. (2004) USA Healthy, postmenopausal women having hot flash activity 88

Richardson et al. (2019) Australia Adolescents diagnosted with delayed sleep-wake phase disorder 103

Ritter et al. (2016) Germany Euthymic outpatients with bipolar disorder and healthy 50

volunteers

Rogers et al. (1993) USA Patients with narcolepsy and matched controls 50

Saline et al. (2016) USA Adult patients referred to a clinical sleep laboratory 643

Santos et al. (2021) Brazil Participants in a longitudinal study 2036

Sato et al. (2010) Japan Patients experiencing psychophysiological insomnia 20

Scarlett et al. (2021) Ireland Community-dwelling older adults 1520

Schneider-Helmert & Kumar (1995)

Switzerland Participants with primary insomnia 128

Schokman et al. (2018) Sri Lanka Sri Lankan adults 175

Schulz & Walther (2017) Germany Individuals referred to a sleep centre for investigation of sleep 117

disorders

Segura-Jimenez et al. (2015)

Spain Women with fibromyalgia and healthy controls 198

Sharkey et al. (2011) USA Patients in a methadone maintenance therapy for opioid 62

dependence

Sharman et al. (2022) United

Kingdom

Healthy sleepers 16

Short et al. (2012) Australia Adolescents 385

Signal et al. (2005) USA Flight crew 21

Silva et al. (2007) USA Participants over 40 2113

Sinclair et al. (2014) Australia Patients with traumatic brain injury and non-injured controls 42

Slightam et al. (2018) USA Veterans with PTSD and demographically similar controls 120

Smagula et al. (2021) USA Males 2850

So et al. (2021) USA Prepubertal children 55

Somma et al. (2020) Italy Participants with insomnia and community dwelling adults 60

matched on demographic variables

Spielmanns et al. (2019) Germany CPAP users 26

Spinweber et al. (1985) USA Laboratory-qualified poor sleepers laboratory-disqualified poor 60

sleepers who were male students at a naval school

Sprajcer et al. (2020) Australia Healthy adult male on-call workers 72

St-Onge et al. (2019) USA Multi-racial, multi-ethnic sample of adults 113

Stout et al. (2017) USA Military veterans and active-duty service members, 17 with 37

PTSD, 20 without PTSD

Sun-Suslow et al. (2022) USA People with and without HIV 94

Takano et al. (2016) Belgium Adults 54

Tang & Harvey (2004) United

Kingdom

Healthy good sleepers 54

Tang & Harvey (2004) (study 2)

United Kingdom

Healthy good sleepers 93

Tang & Harvey (2006) Various Individuals with primary insomnia 48

Tang et al. (2007) United Kingdom

Poor and good sleepers 60

Tang et al. (2007) (study 2)

United Kingdom

Patients with primary insomnia split into a clock-monitoring 38

group and display unit-monitoring group

Thun et al. (2012) Norway University students 166

Thurman et al. (2018) USA Healthy participants 30

Tomita et al. (2013) Japan patients complaining of excessive daytime sleepiness 28

Topalidis et al. (2021) Various Healthy participants 21

Trajanovic et al. (2007) Serbia, USA Patients referred to a sleep clinic 136

Tremaine et al. (2010) Australia Children and adolescents 66

Tremaine et al. (2010) Australia Children aged 11-16 65

Trimmel et al. (2021) Austria Patients with a range of sleep disorders who underwent

laboratory or ambulatory PSG

303

|  |  |  |  |
| --- | --- | --- | --- |
| Trimmel et al. (2021) | Austria | Patients referred to sleep clinic in a department of neurology | 303 |
| Tsuchiyama et al. (2003) | Japan | Patients with major depression admitted to a psychiatric | 23 |

hospital

Usui et al. (2003) Japan Older and younger adults 39

Valko et al. (2021) Switzerland Patients referred to a sleep clinic for PSG 3303

Vallieres & Morin (2003) Canada Participants with chronic primary insomnia 17

Van Den Berg et al. (2008)

Netherlands Community-dwelling older adults 969

Vanable et al. (2000) USA Patients referred to sleep clinic with various sleep disorders 104

Wang et al. (2011) Taiwan Heart failure patients 43

Wang et al. (2022) Canada Naval sailors 66

Werner et al. (2016) USA Women with PTSD experiencing PTSD-related sleep 51

disturbance

|  |  |  |  |
| --- | --- | --- | --- |
| Williams et al. (2011) | USA | Community-dwelling older adults | 142 |
| Wilson et al. (1998) | Canada | Individuals experiencing insomnia associated with chronic | 40 |
| Wilson et al. (2013) | Australia | musculoskeletal pain  Women in third trimester and first trimester of pregnancy and | 64 |
| Winer et al. (2021) | USA | non-pregnant women  Cognitively normal older adults | 89 |
| Wolfson et al. (2003) | USA | High school students | 302 |
| Xu et al. (2022) | China | Young adults | 47 |
| Yamakita et al. (2014) | Japan | School-aged children | 58 |
| Yeung et al. (2015) | China | Individuals with insomnia undergoing placebo acupuncture | 86 |
| Yoon et al. (2022) | Korea | Patients with insomnia | 150 |
| Zak et al. (2022) | USA | Healthy premenopausal women | 71 |
| Zhu et al. (2018) | USA | Adults with type II diabetes | 53 |
| Zinkhan et al. (2014) | Germany | Participants recruited from the community | 100 |
| Zou et al. (2021) | China | Insomnia disorder patients and well-matched healthy controls | 64 |
| te Lindert et al. (2020) | Netherlands | Individuals with insomnia disorder and individuals without | 236 |
|  |  | sleep complaints |  |

Full qualitative methodological details for actigraphy studies are available in Table [6](#_bookmark28).

Table 6: Qualitative actigraphy characteristics

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Study | Actigraph device | Software | Algorithm | Algorithm reference | Rest interval definition |
| 1 | Chou et al. | Actiwatch 2 | Actiware | Actiware | Boyne et al. | Not reported |
| 3 | (2020)  Janků et al. | MotionWatch | MotionWare | Low (20)  MotionWare | (2013)  CamNTech, | Event marker –> sleep |
| 4 | (2020)  King et al. | 8  Actiwatch | not reported | Actiware | UK  Boyne et al. | diary  Not reported |
|  | (2017) | Spectrum |  | Medium | (2013) |  |
| Plus | | | (40) | | | |
| 5 | Lehrer et al. | Actiwatch | Actiware | Actiware | Boyne et al. | Informed by sleep diaries, |
| 7 | (2022)  Segura- | AW64  SenseWear | SenseWear | Medium (40)  SenseWear | (2013)  Lopez et al. | decided by study staff  Set intervals |
|  | Jimenez et | Pro3 | Professional |  | (2017) |  |
|  | al. (2015) | Armband |  |  |  |  |
| 8 | Slightam et | Actiwatch | Actiware | Actiware | Boyne et al. | Event markers –> |
| 10 | al. (2018)  Williams et | AW64  Actiwatch-L | Actiware- | Medium (40)  Actiware | (2013)  Boyne et al. | activity, sleep diary  Not reported |
| 11 | al. (2011)  Al Lawati et | SOMNOwatch | Sleep  Domino | (not reported) Domino | (2013)  Gorny et al. | Manual scoring |
| al. (2021) | | plus | Light | Light | (1996) | |
| 12 | Ansok et al. | Actiwatch | not reported | Cole-Kripke | Cole et al. | Event markers –> sleep |
| 14 | (2020)  Auger et al. | Spectrum Plus Actiwatch | Actiware | Kripke | (1992)  Kripke et al. | diary  Automated –> sleep |
|  | (2013) | AW64 |  |  | (1978) | diary |
| 15 | Baillet et al. | MotionWatch | MotionWare | MotionWare | CamNTech, | Event markers –> sleep |
| 18 | (2016)  Billings | 8  ActiGraph | ActiLife | Cole-Kripke | UK  Cole et al. | diary  Sleep diary, inconsistenies |
| 19 | (2020)  Brychta et | wGT3X-BT  ActiGraph | ActiLife | Sadeh | (1992)  Sadeh et al. | reviewed with participant  Visual inspection, sleep |
| 20 | al. (2019)  Cederberg et | GT3X+  ActiGraph | ActiLife | Cole-Kripke | (1994)  Cole et al. | diaries Sleep diary |
| al. (2022) | | GT3X+ | (1992) | | | |
| 21 | Chan et al. | Actiwatch 2 | not reported | not reported |  | Complex criteria |
|  | (2018) |  |  |  |  | involving sleep diary, |
|  |  |  |  |  |  | activity levels, light |
| 25 | Currie et al. | Mini Motion- | not reported | Cole-Kripke | Cole et al. | Event marker |
| 26 | (2004)  Dietch & | logger Actiwatch | Actiware | Actiware | (1992)  Boyne et al. | Event markers –> sleep |
|  | Taylor (2021) | Spectrum |  | Low (10) | (2013) | diaries –> activity/light patterns |
| 28 | Dunican et | not reported | Readiband | not reported | Not reported | |
| 29 | al. (2017)  Facco et al. | not reported | Sync  not reported | Actiware | Boyne et al. | Not reported |
| 32 | (2018)  Ghadami et | not reported | not reported | Medium (40)  not reported | (2013) | Not reported |
|  | al. (2015) |  |  |  |  |  |
| 33 | Girschik et | Actiwatch | Actiware | Actiware | Boyne et al. | Event marker –> sleep |
| 36 | al. (2012)  Herring et al. | Spectrum  Actiwatch | Actiware | Medium (40)  Actiware | (2013)  Boyne et al. | diary  Event markers –> sleep |
|  | (2013) | AW64 |  | (not | (2013) | diary |
|  |  |  |  | reported) |  |  |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 37 | Hoogerhoud | not reported | not reported | Actiware | Boyne et al. | Not reported |
| 38 | et al. (2015)  Ihler et al. | Actiwatch | Actiwatch | (not reported) Actiware | (2013)  Boyne et al. | Event markers |
|  | (2020) | AW7 | activity & | (not | (2013) |  |
| 39 | Jackowska | Actiheart | sleep analysis Actiheart | reported)  Actiheart | Barreira et | Sleep logs; heart rate; |
|  | et al. (2011) | monitor |  |  | al. (2009) | activity |
| 41 | Kaplan et al. | Actiwatch | Actiware | Actiware | Boyne et al. | Set to lights off and |
|  | (2012) | AW64 |  | (Low, | (2013) | lights-on from PSG |
| 42 | Kawada | Actiwatch | not reported | Medium, High) Actiware | Boyne et al. | Not reported |
| 43 | (2008)  Kay et al. | Actiwatch 2 | Actiware | Medium (40)  Actiware | (2013)  Boyne et al. | Event marker; sleep |
|  | (2015) |  |  | Medium | (2013); Cole | diary; activity; light |
| 44 | Kay et al. | Actiwatch-L | not reported | (40),  Cole-Kripke Actiware | et al. (1992)  Boyne et al. | Not reported |
| (2013) | | High (80) | | | (2013) | |
| 47 | Khou et al. | ActiGraph | ActiLife | Cole-Kripke | Cole et al. | Self-report sleep logs |
|  | (2018) | GT3X+ |  |  | (1992) | compared against |
|  |  |  |  |  |  | ActiLife defined bed and |
|  |  |  |  |  |  | wake times, lux, |
|  |  |  |  |  |  | movement data. If |
|  |  |  |  |  |  | self-report within 30mins |
|  |  |  |  |  |  | of actilife–interval set to |
|  |  |  |  |  |  | self-report, if missing or |
|  |  |  |  |  |  | invalid, ActiLife defined |
|  |  |  |  |  |  | interval used |
| 48  49 | Kong et al. (2011)  Krahn et al. | not reported  not reported | not reported  not reported | not reported  Cole-Kripke | Cole et al. | Not reported  Scored manually (tech |
| 52 | (1997)  Liu et al. | Fitbit Alta | Fitbit | Fitbit | (1992)  Haghayegh | was blinded to sleep diary)  Automatic (heart rate + |
|  | (2019) |  | software |  | et al. (2019) | activity) |
| 53 | Lockley et | Motionlogger, | Action 3 | not reported | Sleep diaries | |
|  | al. (1999) | Mini Motion- |  |  |  | |
| 58 | Mazza et al. | logger  Actiwatch 2 | Actiware | Actiware | Boyne et al. | Event marker, activity, |
|  | (2020) |  |  | Medium | (2013) | light |
|  |  |  |  | (40) |  |  |
| 61 | Moore et al. | Actiwatch 2 | Actiware | Actiware | Boyne et al. | Not reported |
| 62 | (2015)  Most et al. | Actiwatch | Actiware | Medium (40)  Actiware | (2013)  Boyne et al. | Vinyl-covered pressure |
| 63 | (2012)  Mundt et al. | Actiwatch 2 | Actiware | (not reported) Actiware | (2013)  Boyne et al. | sensitive pad and  light-dependent resistor Sleep diaries |
| 65 | (2016)  Nazem et al. | Actiwatch 2 | Actiware | High (80)  Actiware | (2013)  Boyne et al. | Not reported |
| 67 | (2016)  Okifuji & | Micro Mini | Action | (not reported) not reported | (2013) | Not reported |
|  | Hare (2011) | Motionlog- |  |  |  |  |
|  |  | ger |  |  |  |  |
| 68 | Orta et al. | ActiSleep | ActiLife | Cole-Kripke | Cole et al. | Not reported |
|  | (2016) |  |  |  | (1992) |  |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 71 | Regestein et | not reported | not reported | Actiware | Boyne et al. | Sleep diary |
| 72 | al. (2004)  Ritter et al. | SOMNOWatch | Domino | Medium (40)  Cole-Kripke | (2013)  Cole et al. | Event markers |
| 74 | (2016)  Sato et al. | Plus  not reported | Light  not reported | Cole-Kripke | (1992)  Cole et al. | Not reported |
| (2010) | | (1992) | | | | |
| 76 | Sharman et | Actiwatch | Actiwatch | Actiware | Boyne et al. | Event markers –> sleep |
|  | al. (2022) | AW4 | Activity and | Medium | (2013) | diary, verification from |
|  |  |  | Sleep | (40) |  | audio file timestamps |
|  |  |  | Analysis |  |  |  |
| 78 | Spielmanns | PAM Polar | not reported | not reported |  | N/a |
|  | et al. (2019) | A300 |  |  |  |  |
| 82 | Wang et al. | Micro Mo- | Action 4 | not reported | Event markers | |
| 83 | (2022)  Werner et al. | tionlogger not reported | Action W | UCSD | Jean-Louis | Automatic |
| (2016) | | et al. (2001) | | | | |
| 87 | Barbosa et | ActiGraph | ActiLife | Cole-Kripke | Cole et al. | Sleep diary, activity, light |

al. (2017)

GT3X+

(1992)

1. Broomfield & Espie (2003)

Actiwatch 2 not reported not reported Event markers

1. Caia et al. (2018)

Actiwatch 2, ActiGraph GT3X+,

Readiband

not reported not reported Not reported

1. Campanini

et al. (2017)

Actiwatch 2 Actiware Actiware

Medium (40)

Boyne et al. (2013)

Algorithms supplemented by event marker

1. Carter et al. (2020)

Actiwatch Spectrum Pro

not reported Actiware

Medium (40)

Boyne et al. (2013)

Light

97 Chung et al. (2020)

Actiwatch 2 Actiware Actiware

Medium (40)

Boyne et al. (2013)

Event marker or sleep diary

98 Dautovich et

al. (2008)

Actiwatch-L Actiware-

Sleep

Actiware High (80)

Boyne et al. (2013)

Naps identified in sleep diaries, Webster’s rules (daily sleep logs, notes, illumination channel)

99 De Jaeger et al. (2019)

Actiwatch Spectrum Plus

Actiware Actiware (not reported)

Boyne et al. (2013)

Not reported

100 Dean et al. (2019)

Octagonal Action 3 not reported Sleep diary Sleep Watch

104 Gonzalez et

al. (2013)

Motionlogger Action UCSD Jean-Louis

et al. (2001)

Not reported

105 Goudman et

al. (2018)

Actiwatch Spectrum Plus

Actiware Actiware (not reported)

Boyne et al. (2013)

Not reported

107 Hanisch et

al. (2011)

Actiwatch AW64

Actiware- Sleep

Actiware (not reported)

Boyne et al. (2013)

Sleep diary

1. Hughes et al. (2018)

Actiwatch Spectrum

not reported Actiware

Medium (40)

Boyne et al. (2013)

Not reported

1. Kaufmann

et al. (2019)

Actisleep- BT

not reported not reported Not reported

1. Kreutz et al. (2021)

ActiGraph wGT3X-BT

ActiLife Cole-Kripke, Tudor-Locke

Cole et al. (1992);

Tudor-Locke et al. (2014)

Tudor-Locke algorithm

1. Krishnamurthy not reported ActiLife ActiLife Peach et al. Not reported

et al. (2018) (2014)

118 Lauderdale

et al. (2008)

Actiwatch AW16

not reported not reported Event markers –> sleep log

119 Lubas et al. Motionlogger not reported not reported Event markers

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 120 | (2022)  Maich et al. | Actiwatch | Mini-Mitter | Actiware | Boyne et al. | Not reported |
| 126 | (2018)  Okun et al. | Score  Actiwatch | Actiwatch Software Actiware | Low (20)  Actiware | (2013)  Boyne et al. | Autointerval option with |
| 127 | (2021)  Park et al. | Actillume I | Actillume | Medium (40)  Actillume | (2013)  Jean-Louis | event markers  Sleep diary, notes, light, |
| 131 | (2007)  Scarlett et | GENEactiv | Algorithm  GENEactive | Micro- | et al. (2001)  Dunne et al. | Webster’s rules  N/a |
|  | al. (2021) |  |  | Electro- | (2013) |  |
|  |  |  |  | Mechanical |  |  |
|  |  |  |  | Systems |  |  |
| 132 | Schokman et | Actiwatch | Actiware | Actiware | Boyne et al. | Manual: visual |
|  | al. (2018) | Spectrum |  | Medium | (2013) | inspection, sleep diary |
|  |  | Pro |  | (40) |  | entry, Actiwatch |
|  |  |  |  |  |  | timestamps (according to neurosleep manual) |
| 133 | Stout et al. | Micro Sleep | not reported | not reported | Not reported | |
| 134 | (2017)  Tang & | Watch  Mini Motion- | not reported | Cole-Kripke, | Cole et al. | Defined in-lab |
|  | Harvey | logger Basic |  | Webster’s | (1992) |  |
| 135 | (2004)  Thun et al. | Actiwatch | Actiwatch | rescoring rules Actiware | Boyne et al. | Not reported |
|  | (2012) | AW7 | Activity and | Medium | (2013) |  |
| 136 | Tomita et al. | MicroMini | Sleep Analysis Action W2 | (40)  not reported |  | Manually corrected, using |
|  | (2013) | RC |  |  |  | diaries where necessary |
| 137 | Tremaine et | not reported | Actiware- | Actiware | Boyne et al. | Not reported |
| 139 | al. (2010)  Usui et al. | Motionlogger | Sleep  not reported | Medium (40)  Cole-Kripke | (2013)  Cole et al. | N/a |
| 142 | (2003)  Wilson et al. | Mini Motion- | not reported | Cole-Kripke, | (1992)  Cole et al. | Not reported |
|  | (1998) | logger |  | Webster’s | (1992) |  |
| 143 | Wolfson et | Mini Motion- | Action W2 | rescoring rules Sadeh | Sadeh et al. | Sleep diary |
| 144 | al. (2003)  Yamakita et | logger  Lifecorder | Sleep Sign | Sleep Sign | (1994)  Kissei | Set manually |
|  | al. (2014) |  | Act | Act | Comtec Co, |  |
|  |  |  |  |  | Japan |  |
| 145 | Yeung et al. | Actiwatch 2 | Actiware, | Actiware | Boyne et al. | Not reported |
| 148 | (2015)  Baek et al. | Actiwatch | Action W  Actiware | (not reported) Actiware | (2013)  Boyne et al. | Sleep diary |
| 149 | (2020)  Chan et al. | Spectrum Pro Actiwatch-L | Actiware- | Medium (40)  Actiware | (2013)  Boyne et al. | Sleep diary |
|  | (2021) |  | Sleep | Medium (40) | (2013) |  |
| 150 | Chen et al. | not reported | not reported | not reported | Not reported | |
| 154 | (2015)  Heath et al. | Micro Mini | Action W2 | Sadeh | Sadeh et al. | Not reported |
|  | (2018) | Motionlog- |  |  | (1994) |  |
|  |  | ger |  |  |  |  |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 156  157 | Kobayashi et al. (2012)  McCall & | Mini Motion- logger Actiwatch | Action W2  Actiware | Sadeh  Actiware | Sadeh et al. (1994)  Boyne et al. | Sleep diary, habitual sleep questionnaire Not reported |
| 159 | McCall (2012)  Vallieres & | AW64  IM Systems | Individual | Medium (40)  IM Systems | (2013)  Individual | Not reported |
|  | Morin | Actigraph | Monitoring |  | Monitoring |  |
| 160 | (2003)  Zhu et al. | ActiGraph | Systems  ActiLife | Actiware | Systems, Inc., USA  Boyne et al. | Not reported |
|  | (2018) | wGT3X |  | Medium | (2013); Cole |  |
| 161 | Hall et al. | Motionlogger | Action W | (40),  Cole-Kripke UCSD | et al. (1992)  Jean-Louis | N/a |
|  | (2022) | Basic |  |  | et al. (2001) |  |
| 163 | Kolling et al. | SenseWear | SenseWear | SenseWear | Lopez et al. | Event marker –> activity |
| 164 | (2016)  Locihova et | MF  Armband ActiGraph | Professional  ActiLife | Cole-Kripke | (2017)  Cole et al. | Externally defined |
| 167 | al. (2020)  Winer et al. | wGT3X-BT  Micro Mo- | Action W2 | Sadeh | (1992)  Sadeh et al. | Sleep diary and event |
| 168 | (2021)  D’Aoust et | tionlogger Actiwatch-L | Actiware | Actiware | (1994)  Boyne et al. | markers Sleep diary |
| 169 | al. (2015)  Dinapoli et | SenseWear | SenseWear | (not reported) SenseWear | (2013)  Lopez et al. | Not reported |
|  | al. (2017) | MF |  |  | (2017) |  |
|  |  | Armband |  |  |  |  |
| 170 | Dorrian et | not reported | Actiware- | Actiware | Boyne et al. | Not reported |
| 173 | al. (2012)  O’Brien et | Motionlogger | Sleep  Action W | Medium (40)  Sadeh | (2013)  Sadeh et al. | Sleep diary, discrepancies |
|  | al. (2016) | Basic |  |  | (1994) | queried |
| 174 | St-Onge et | ActiGraph | not reported | not reported | Not reported | |
|  | al. (2019) | GT3X+ |  |  |  |  |
| 176 | Arora et al. | ActiGraph | not reported | not reported | Sleep diary | |
| (2013) | | GT3X+ | | | | |
| 180 | Curtis et al. | Actiwatch 2 | Actiware | Actiware | Boyne et al. | Sleep diary |
|  | (2019) |  |  | (not | (2013) |  |
|  |  |  |  | reported) |  |  |
| 181 | Devine et al. | Actiwatch 2 | Actiware | Actiware | Boyne et al. | Automatically defined, |
| 183 | (2020)  Dzierzewski | Actiwatch | not reported | Medium (40)  Actiware | (2013)  Boyne et al. | sleep diary/ other daily schedule info  Not reported |
| 184 | et al. (2019)  Etain et al. | Spectrum  Actiwatch | Actiwatch | (not reported) Actiware | (2013)  Boyne et al. | Sleep diary and event |
|  | (2021) | AW7 | Activity and | (not | (2013) | markers |
| 186 | Gibson et al. | ActiGraph | Sleep Analysis ActiLife | reported)  Cole-Kripke | Cole et al. | Externally defined |
| 187 | (2022)  Gökce et al. | GT9X Link ActiGraph | Actiware | Cole-Kripke | (1992)  Cole et al. | (platoon sleep record) Software-defined |
|  | (2020) | wGT3X-BT |  |  | (1992) |  |
| 188 | Herbert et | MotionWatch | MotionWare | Sadeh | Sadeh et al. | Sleep diary |
| 191 | al. (2017)  Jackson et | 8  Actiwatch | Actiware- | Actiware | (1994)  Boyne et al. | Event marker, sleep diary, |
|  | al. (2018) | Spectrum | Sleep | (not | (2013) | light sensor |

193 Kung et al. (2015)

Mini Motion- logger

reported)

Action W2 not reported Externally-defined (lights on/off times at psychiatric ward)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 196 | Lee (2021) | ActiGraph | not reported | Machine | John et al. ( | Not reported |
| 199 | Meyer et al. | GT3X+  Fitbit | Sleepsight | learning algorithm Fitbit | 2019)  Haghayegh | N/a |
|  | (2018) | Charge HR |  |  | et al. (2019) |  |
| 200 | Kishikawa et | Actiwatch 2 | Actiware | Actiware | Boyne et al. | Event markers |
|  | al. (2021) |  |  | Medium | (2013); Cole |  |
|  |  |  |  | (40),  Cole-Kripke | et al. (1992) |  |
| 201 | Santos et al. | Actiwatch 2 | not reported | not reported | Event marker | |
| 203 | (2021)  Smagula et | SleepWatch- | Action W2 | Cole-Kripke, | Cole et al. | Sleep diary –> manual |
|  | al. (2021) | O |  | UCSD | (1992); | scoring |
| 204 | te Lindert et | GENEactiv | GENEactive | Actiware | Jean-Louis et al. (2001) Boyne et al. | Sleep diary |
|  | al. (2020) |  |  | (Low, | (2013) |  |
| 205 | Thurman et | Readiband | Fatigue | Medium, High) Fatigue | Russel et al. | Sleep offset/onset defined |
|  | al. (2018) | Actigraph | Science | Science | (2016) | by sleep state |
|  |  | SBV2 | Software |  |  | (9pm-11am) |
| 206 | Topalidis et | Xiaomi Mi | ActiLife | Cole-Kripke | Cole et al. | N/a |
|  | al. (2021) | Band 3, |  |  | (1992) |  |
| 207 | Van Den | GT3X  ActiGraph Actiwatch | Actiware | Actiware | Boyne et al. | Event marker –> sleep |
| 208 | Berg et al. (2008)  Zak et al. | AW4  Mini Motion- | Action | Low (20)  Cole-Kripke | (2013)  Cole et al. | diary  Event marker |
|  | (2022) | logger, |  |  | (1992) |  |
|  |  | Actigraph |  |  |  |  |
|  |  | Model AAM-32 |  |  |  |  |
| 209 | De | ActiGraph | not reported | not reported | Not reported | |
|  | Francesco et | wGT3X-BT |  |  |  | |
| 210 | al. (2021)  Gaina et al. | Actiwatch | not reported | not reported |  | Sleep diary |
|  | (2004) |  |  |  |  |  |
| 211 | Guedes et al. | Mini Motion- | Action W2 | Sadeh | Sadeh et al. | Sleep/activity log |
| 213 | (2016)  Sinclair et al. | logger Basic not reported | Actiware | Actiware | (1994)  Boyne et al. | Sleep diary |
| 214 | (2014)  Takano et al. | ActiGraph | Actiware | Medium (40)  Cole-Kripke | (2013)  Cole et al. | Unsure/ not reported |
| 215 | (2016)  Tang et al. | wGT3X-BT  Mini Motion- | Action W | Cole-Kripke | (1992)  Cole et al. | Webster’s rules (daily |
| 216 | (2007)  Tang & | logger Basic  Mini Motion- | Action W | Cole-Kripke | (1992)  Cole et al. | sleep logs, notes, illumination channel) Webster’s rules (daily |
|  | Harvey | logger Basic |  |  | (1992) | sleep logs, notes, |
|  | (2006) |  |  |  |  | illumination channel) |
| 217  219 | Wang et al. (2011)  Creti et al. | Motionlogger  Actitrac | Action W2  IM Systems | not reported  IM Systems | Individual | Not reported  Externally set (PSG) |
|  | (2010) |  | Software |  | Monitoring |  |
| 222 | He et al. | ActiGraph | ActiLife | Cole-Kripke, | Systems, Inc., USA  Cole et al. | N/a or not reported |
|  | (2021) | wGT3X-BT |  | Choi, | (1992); Choi |  |
|  |  |  |  | Troiano | et al. (2011); |  |
|  |  |  |  |  | Troiano et al. |  |
|  |  |  |  |  | (2007) |  |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 223  224 | Hur et al. (2020)  Jungquist et | ActiGraph wGT3X-BT  Camntech | ActiLife  MotionWare | Cole-Kripke  MotionWare | Cole et al. (1992)  CamNTech, | Sleep diaries  Not reported |
|  | al. (2016) | Pro-Diary |  |  | UK |  |
| 230  231 | Short et al. (2012)  So et al. | Motionlogger  Micro Mo- | Action W2  not reported | Sadeh  Sadeh | Sadeh et al. (1994)  Sadeh et al. | Sleep diary  Event marker |
| (2021) | | tionlogger | (1994) | | | |
| 233 | Sun-Suslow | ActiGraph | not reported | Cole-Kripke | Cole et al. | Sleep diary –> manual |
| 234 | et al. (2022) Tremaine et | GT9X Link not reported | Actiware- | Actiware | (1992)  Boyne et al. | Sleep diary |
| 235 | al. (2010)  Jackson et | ActiGraph | Sleep  ActiLife | Medium (40)  Cole-Kripke | (2013)  Cole et al. | Manual: sleep diary, |
|  | al. (2019) | GT3X+ |  |  | (1992) | activity, light |
| 237 | Bean et al. | Actiwatch | Cambridge | Actiware | Boyne et al. | Sleep diary |
|  | (2021) | AW64 | Neurotech- | (not | (2013) |  |
| 238 | Miner et al. | SleepWatch- | nology Sleep Analysis 5.5 Action W2 | reported)  UCSD | Jean-Louis | Software and sleep diaries |
| 239 | (2022)  Richardson | O  Micro Mini | not reported | Sadeh | et al. (2001) Sadeh et al. | Manual and sleep diary |
| 241 | et al. (2019)  Friedmann | Motionlog- ger  Move II | not reported | Barouni | (1994)  Barouni et | Sleep onset during fixed |
| 243 | et al. (2022) Signal et al. | Actiwatch | Actiware- | Actiware | al. (2020)  Boyne et al. | interval: 20:00-00:00 Event marker, sleep diary |
|  | (2005) |  | Sleep | (Low, | (2013) |  |
|  |  |  |  | Medium, |  |  |
|  |  |  |  | High) |  |  |
| 244  245 | Narisawa et al. (2015)  Tang & | Actiwatch  Mini Motion- | not reported  not reported | not reported  Cole-Kripke | Cole et al. | Activity levels  Defined in-lab |
|  | Harvey | logger Basic |  |  | (1992) |  |
| 248 | (2004)  (study 2) Tang et al. | Mini Motion- | Action W | Cole-Kripke | Cole et al. | Webster’s rules (daily |
|  | (2007) | logger Basic |  |  | (1992) | sleep logs, notes, |
|  | (study 2) |  |  |  |  | illumination channel) |

*Note:* The –> arrow designates the priority given to methods of calculating the rest interval. For example, event markers –> activity, sleep diary, indicates that event marker presses were first used to calculate rest intervals, followed by sleep diary and activity when event marker presses were not available.

A full list of studies that recorded sleep-wake agreement is available in Table [7](#_bookmark29) below.

Table 7: Direct sleep-wake agreement studies

Study Sample characteristics Sleep variables Sleep-wake agreement type

PSG setting

60 Mendelson

et al. (1986)

individuals with insomnia and age and sex matched controls

TST, sleep after experimental awakenings, awake/asleep upon awakening (binary)

Binary in-lab

73 Rogers et al. (1993)

patients with narcolepsy and matched controls

Sleep/wake agreement (15-minute blocks), 3 time periods (spanning 24hr) transition (lights on/off), sleep period, daytime

Confusion matrix

home-based

101 Dorsey & Bootzin (1997)

undergraduate students SOL (MSLT), sleep / wake

agreement [Terminal sleep stage at each sleep latency test (objective), estimated conscious state by subject (subjective)]

Confusion matrix

in-lab

123 Mendelson

(1998)

124 Mercer et al. (2002)

participants who complained of poor sleep

individuals with insomnia and good sleepers

Participant report of having been awake/asleep following experimental awakenings

home PSG: TST, SOL, WASO,

SE; lab: signal detection for PSG-wake as signal (exp awakenings), TST, sleep between probes

Binary in-lab

Binary in-lab, home-based

139 Usui et al. (2003)

older and younger adults sleep/ wake agreement, 10-minute epochs

Confusion matrix

n/a

152 Downey & Bonnet (1992)

subjective insomniacs SOL, participant sleep/wake

judgement following experimental awakenings

Binary in-lab

165 Nguyen- Michel et al. (2015)

older adults referred for insomnia complaints or suspected sleep apnoea

Perception of sleep during nap (binary)

Binary in-lab

170 Dorrian et

al. (2012)

commercial passenger airline pilots

TST; sleep/wake Confusion matrix

n/a

229 Schulz & Walther (2017)

individuals referred to a sleep centre for investigation of sleep disorders

sleep / wake judgement following induced awakenings

Binary in-lab

*Note:* Binary sleep-wake involved measuring at one or multiple instances whether a participant’s reported sleep state matched the objective sleep state upon which the query was conditional (e.g., participants were only queried dur- ing objectively-confirmed sleep). On the other hand, confusion matrix sleep-wake involved measuring at one or multiple instances whether a participant’s reported sleep state matched an objective sleep state that was allowed to vary inde- pendent of the query (e.g., participants were queried at a certain time point irrespective of sleep state). The states were called so as the former approach produces a binary outcome whereas the latter produces a confusion matrix.

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