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

Tom F. Walton1

Melissa J. Ree1

Simone N. Fueggle2

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Romola S. Bucks1,3,4

1 School of Psychological Science, The University of Western Australia

2 CALHN Neuropsychology, Royal Adelaide Hospital

3 School of Population and Global Health, The University of Western Australia

4 Oﬀice of the Deputy Vice Chancellor, Research, The University of Western Australia

1. **Abstract**
   1. **Study Objectives**

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

* 1. **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).

* 1. **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.

* 1. **Conclusions**

Sleep discrepancy was predominantly 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.

* 1. **Key words**

Sleep discrepancy; sleep misperception; scoping review

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**1.6 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.

**2**

**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 consid- ered 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 with a range of 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 analyses. Other studies may calculated derived 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 limited systematic attempts to synthesise or evaluate the varied approaches to investigating 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.

2

1. **Methods**
   1. **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)).

* 1. **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.

* 1. **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, (vii) were a grey literature source including theses, dissertations, and conference abstracts, or (viii) were not available in English. No records were excluded on the basis of geographic location, cultural factors, or any other contextual feature.

* 1. **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 appendices for full search strategies for other databases.

* 1. **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 after protocol registration.

* 1. **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

3

Table 1: Search strategy for Embase (Ovid)

Step

1

Terms and Operators

sleep discrepancy or paradoxical insomnia or subjective insomnia or (sleep adj2

Records

488

misperception).mp

((self report\* or diary or subjective\*) and (objective\* or actigraph\* or polysomnograph\* or polygraph\*)).mp.

(exp polysomnography/ or exp actimetry/) and exp self report/

(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.

2 or 3

4 and 5

1 or 6

2

3

4

193243

1676

9362

5

6

7

193302

1234

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.

* 1. **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/data/codebook.xlsx>.

* 1. **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>.

**4**

**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).

4



Figure 1: PRISMA flowchart

**4.1 Article characteristics**

A total of 248 studies was 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](#_bookmark28))

5

Total studies included in review (n = 244)

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)

Reports sought for retrieval (n = 655)

Records excluded (n = 1,641)

Records screened (n = 2,296)

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)

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

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

2

2

2

2

2

2

2

2

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2

1

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1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

0

20

40

Number of studies

60

80

Figure 2: Sample characteristics

6

Sample characteristics

* 1. **Methodological features**
     1. **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

EEG (including PSG)

116

0

50

100

Number of studies

150

Figure 3: Measures of objective sleep

**4.2.1.1 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

Oxford screen scoring method

R&K and Mendelson SS90−III Sleep Stager System

Criteria not reported

56

45

1

1

1

5

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).

7

Scoring Criteria

In−lab Home−based

In−lab & home−based

fMRI

Airline rest facility

Truck−berth PSG setting not reported

86

18

3

1

1

1

2

0

25

50

Number of studies

75

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

MSLT

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

Repeated naps across 28−hour period

98

3

1

1

1

1

1

1

0

30

60

Number of studies

90

Figure 6: PSG recording period

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

**4.2.1.2 Actigraphy** We recorded features of actigraphy including device name, scoring algorithm, soft- ware, and rest interval definition. See Table [6](#_bookmark29) 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).

8

Period

Setting

Actiware Cole−Kripke

Sadeh UCSD

SenseWear MotionWare

Webster's rescoring rules

IM Systems

Fitbit Tudor−Locke

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

Kripke Fatigue Science Domino Light

Choi Barouni Actillume ActiLife Actiheart

Algorithm not reported

54

32

11

5

3

3

2

2

2

1

1

1

1

1

1

1

1

1

1

1

1

1

25

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

80 activity counts (High)

3

40 activity counts (Medium)

28

20 activity counts (Low)

3

10 activity counts (Low)

1

Actiware wake threshold not reported

16

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).

9

Actiware threshold

Algorithm

Sleep diary Event marker press

Manual judgements of activity

Light sensor External parameters such as set bed and rise times

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

Heart rate

Rest interval not reported

60

29

21

16

11

10

2

1

1

1

1

42

0

20

40

Number of studies

60

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](#_bookmark29) 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.

**4.2.2 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

Graphical sleep diary

10

Questionnaire on awakening

75

Interview on awakening

4

Graphical response on awakening

1

Pittsburgh Sleep Quality Index (PSQI)

37

Habitual sleep questionnaire (other than PSQI)

17

0

25

50

75

100

125

Number of studies

Figure 10: Measures of self-report sleep

10

Rest interval

Habitual sleep questionnaire

Query on awakening

Sleep diary

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

Habitual and episodic sleep

7

Episodic sleep

187

0

50

100

Number of studies

150

Figure 11: Habitual or episodic sleep

**4.3 Sleep variables**

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

11

Total sleep time (TST)

197

Sleep onset latency (SOL)

142

Wake after sleep onset (WASO)

73

Sleep efficiency (SE)

65

Time in bed (TIB)

21

Number of awakenings (NWAK)

27

Total wake time (TWT)

7

Sleep period time (SPT)

5

Sleep onset time (SOT)

13

Final wake time (FWT)

19

Bed time (BT)

14

Rise time (RT)

2

Sleep midpoint

2

Binary Sleep−Wake agreement

6

Confusion Matrix Sleep−Wake agreement

4

Latency to persistent sleep (LPS)

3

Sleep during subjective latency (SDSL)

2

Latency−adjusted total sleep time (LA−TST)

1

Effective sleep time (EST)

1

Subjective wake time (SWT)

1

Intermittent wake time (IWT)

1

0

50

100

Number of studies

150

200

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 rise time (RT). BT 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.

12

Sleep variable

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.

**4.3.1 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

TIB−SOL−WASO−TWAK

18

TIB−TWT

4

TIB−WASO

1

FA−LO

2

FWT−SOT

1

SPT−SOL−WASO

3

Calculated (calculation not reported)

5

Graphical responses

7

Not reported

33

0

50

Number of studies

100

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.

13

Variable definitions

Direct query

39

TIB−TST−SOL

2

Number of awakenings \* average length of awakenings

1

Calculated (not reported)

1

Graphical responses

3

Definition not reported

30

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

46

FA−LO

4

TST + WASO + SOL

1

Graphical responses

1

Direct query

1

Definition not reported

12

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).

**4.3.2 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.

14

Variable definitions

Variable definitions

Actigraphy−defined

71

First epoch of any sleep stage (standard AASM)

26

First 3 consecutive epochs of stage 1 or first epoch of any

other sleep (R&K)

22

First epoch Stage 2

8

First 20 consecutive epochs any stage of sleep (LPS)

6

First sleep spindle

2

First epoch Stage 1

1

First epoch SWS

1

First 3 consecutive epochs of sleep

1

First 2 consecutive epochs of Stage 2

1

First 10 consecutive epochs Stage 2

1

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

1

1

1

Video observation

1

Parameter varied in model

1

SOL definition not reported

6

0

20

40

Number of studies

60

80

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.

**4.3.3 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

15

SOL definition

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.

**4.4 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)

Means of sleep variables

96

Modes of sleep variables

2

Medians of sleep variables

1

Means of derived indices

12

Standard deviations of derived indices

1

Repeated measures ANOVA

13

Linear mixed models

10

Generalised estimating equations

1

Structural equation modelling

1

Repeated measures correlation

1

Pooled observations

13

Separate analyses

8

Single recording instance

75

0

25

50

Number of studies

75

100

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.

**4.5 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)

16

Method of handling repeated measurements

Pearson or Spearman correlations

96

Bland Altman Analyses

59

Paired t−tests or Wilcoxon Signed Rank tests

ANOVA

Linear models

52

20

15

Intraclass Correlation

13

Cohen's Kappa Classification performance measures

1−sample t−tests of difference scores

10

9

7

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

Pitman's tests

3

2

2

Lin's Concordance Coefficient

2

Independent samples t−tests

Other direct comparison (described below)

2

8

0

30

60

Number of studies

90

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).

* 1. **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 at the individual level through the calculation of a derived index.

* + 1. **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

17

Methods for direct sleep comparisons

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.

18

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

oSE−sSE

sAwakenings−oAwakenings

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

48

39

17

12

9

8

7

5

4

3

2

2

2

1

1

1

1

|sTST−oTST|

|sSOL−oSOL|

|sWASO−oWASO|

|sSPT−oSPT|

|sSE−oSE|

7

3

1

1

1

(sTST/oTST)\*100

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

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

sSE/oSE

15

6

6

4

3

3

2

1

1

1

(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

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

19

Absolute difference scores

Arithmetic difference scores

Combination scores

Ratio scores

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.

**4.6.2 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

7

Classification performance in statistical analysis

10

Differences between correlations

3

Modelled parameter

4

0.0

2.5

5.0

7.5

10.0

12.5

Number of studies

Figure 20: Other methods for operationalising sleep discrepancy

**4.7 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.

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Method

**5**

**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 diverse 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.

**5.1 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 who 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 methodological differences do not correspond to distinct concepts, methodological choices are arbitrary and introduce undue uncertainty into inferences (see, Hoffmann et al., 2021). This can be a significant problem. For studies

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investigating the relationship 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.

* 1. **Methodological heterogeneity may influence the rate of false-positive find- ings**

Methodological diversity may also have consequences for 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 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.

* 1. **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

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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).

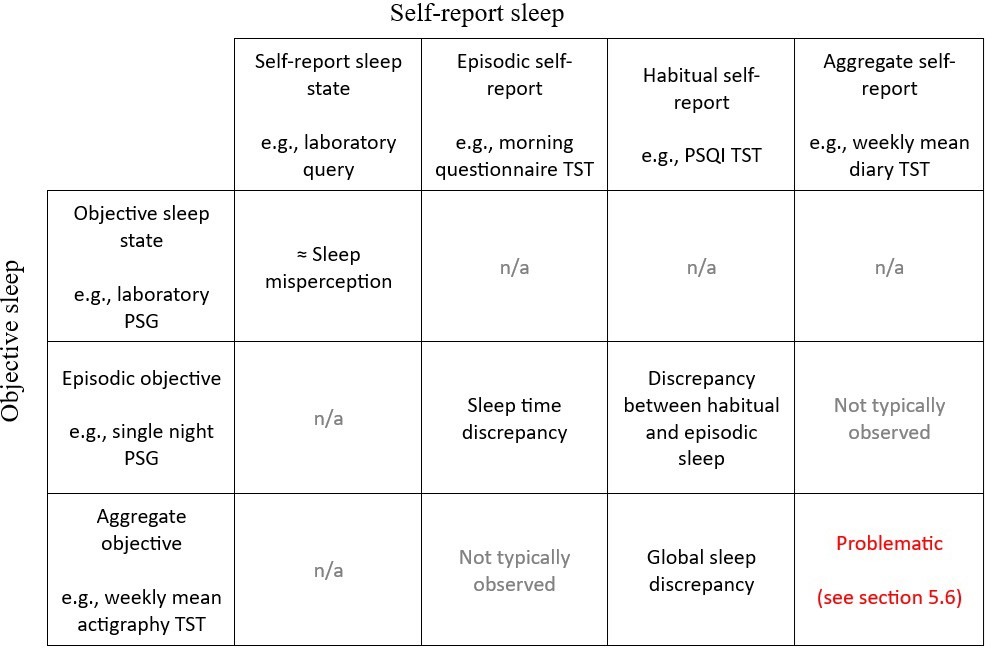
Options 2 and 3 have the added advantage of operationalising sleep discrepancy without the use of derived scores—the problems with which are discussed briefly in a following paragraph.

**5.4 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 interchangeably 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 alternating 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 from 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

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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)

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* 1. **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 is 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.

* 1. **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.

* 1. **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.

* 1. **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

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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.

* 1. **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.

* 1. **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).

* 1. **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.

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**5.12 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**

Further research is necessary to determine where methodological differences in sleep discrepancy ap- proaches indicate meaningful conceptual differences

The impact of varying justified approaches to measuring and operationalising sleep discrepancy should be assessed

Integrated and standardised approaches to conducting actigraphy would benefit sleep discrepancy re- search by reducing methodological heterogeneity

Open science practices including pre-registration and research transparency have the potential to im- prove sleep discrepancy research

**5.13**

1.

2.

3.

4.

**5.14 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.

**6 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).

**7**

**Acknowledgements**

We would like to thank the librarians at the University of Western Australia library for their assistance with the development of the search strategy.

**8**

**Financial disclosure statement**

None.

**9**

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27

**10**

**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.

28

1. **Appendices**
   1. **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

2

3

4

sleep discrepancy or paradoxical insomnia or subjective insomnia or (sleep adj2 misperception).mp

((self report\* or diary or subjective\*) and (objective\* or actigraph\* or polysomnograph\* or polygraph\*)).mp.

(exp polysomnography/ or exp actimetry/) and exp self report/

(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.

2 or 3

4 and 5

1 or 6

488

193243

1676

9362

5

6

7

**PsycINFO**

1

2

3

4

193302

1234

1569

sleep discrepancy or paradoxical insomnia or subjective insomnia or (sleep adj2 misperception).mp

((self report\* or diary or subjective\*) and (objective\* or actigraph\* or polysomnograph\* or polygraph\*)).mp.

(exp polysomnography/ or exp actigraphy/) and exp self report/

(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.

2 or 3

4 and 5

1 or 6

175

57592

59

2112

5

6

7

57592

346

471

**Medline**

1

2

3

4

sleep discrepancy or paradoxical insomnia or subjective insomnia or (sleep adj2 misperception).mp

((self report\* or diary or subjective\*) and (objective\* or actigraph\* or polysomnograph\* or polygraph\*)).mp.

(exp polysomnography/ or exp actigraphy/) and exp self report/

(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.

2 or 3

4 and 5

1 or 6

260

139088

561

5280

5

6

7

139088

692

875

29

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\*))

(”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\*))

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\* ) ) )

(”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\*)) noft((”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

CINAHL

310

Scopus

826

Web of Science

1288

Proquest Theses and Dissertations Global

90

30

* 1. **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

31

**11.3 PRISMA-ScR checklist**

A PRISMA-ScR checklist is available in Table [4](#_bookmark27).

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

**Abstract**

Structured summary

1

Identify the report as a scoping review.

1

2

Provide a structure summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.

1

**Introduction**

Rationale

3

Describe the rationale for the review in the context of what is already known. Explain why the review questions/ objectives lend themselves to a scoping review approach

Provide an explicit statement of the questions and objectives being 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.

2

Objectives

4

2

**Methods**

Protocol and registrations

Eligibility criteria

5

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.

Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.

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.

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

State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.

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.

List and define all variables for which data were sought and any assumptions and simplifications made

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).

Describe the methods of handling and summarizing the data that were charted

3.1

6

3.2

Information sources

Search

Selection of sources of evidence

Data charting process

7

3.4

8

9

10

3.1

3.5

3.6

Data items

Critical appraisal of individual sources of evidence

Synthesis of results

11

12

3.7

Formal quality assessment was not conducted

3.8

13

**Results**

Selection of sources of evidence

Characteristics of sources of evidence Critical appraisal

within sources of evidence

Results of individual sources of evidence

14

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.

For each source of evidence, present characteristics for which data were charted and provide the citations.

If done, present data on critical appraisal of included sources of evidence (see item 12).

4

15

16

11.4

Formal quality assessment was not conducted

4.2

17

For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.

32

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

Section

Item

PRISMA-ScR Checklist Item

Location reported

Synthesis of results

18

Summarize and/or present the charting results as they relate to the review questions and objectives.

4.2

**Discussion**

Summary of evidence

Limitations Conclusions

19

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

Discuss the limitations of the scoping review process.

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

20

21

5.11

5.12

**Funding**

Funding

22

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

9

33

**11.4 Additional tables**

Full descriptions of study characteristics are available in Table [5](#_bookmark28).

Table 5: Characteristics of included studies

Study

Country of origin

Sample characteristics

Sample size

Ahn et al. (2021)

Al Lawati et al. (2021) Alameddine et al. (2015) Ansok et al. (2020) Argyropoulos et al. (2003)

Aritake-Okada et al. (2010)

Arora et al. (2013)

Auger et al. (2013) Baek et al. (2020) Baillet et al. (2016)

Korea Oman USA USA

United Kingdom

Japan

United Kingdom USA

Korea France

Patients >55 years with insomnia disorders Healthy Omani nationals

Participants referred to a sleep centre for PSG Patients with rotator cuff tears

Outpatients with moderate to severe depression, without psychotic features, in an RCT of two antidepressants

Healthy males Adolescents aged 11-13

Patients referred to an academic sleep centre Shiftwork nurses

Older adults with no sleep disorders, sleep medications, or depressive symptomatology

Healthy young subjects

Visually impaired individuals and participants without visual impairment

Individuals with chronic psychophysiological insomnia, paradoxical insomnia and good sleepers

Chronic pain patients

Participants with comborbid insomnia and OSA

33

321

879

18

40

22

255

84

94

45

Baker et al. (1999) Barbosa et al. (2017)

Bastien et al. (2013) Bean et al. (2021)

Bensen-Boakes et al. (2022)

Bian et al. (2016) Bianchi et al. (2012) Bianchi et al. (2013) Billings (2020)

Bonnet & Moore (1982)

Broomfield & Espie (2003)

Brychta et al. (2019) Caia et al. (2018) Campanini et al. (2017) Carter et al. (2020)

Castelnovo et al. (2021) Castillo et al. (2014) Cederberg et al. (2022) Chan et al. (2018) Chan et al. (2021)

Chen et al. (2015) Chervin & Guilleminault (1996)

Cho et al. (2022) Choi et al. (2016)

Chou et al. (2020)

Chung et al. (2020) Combertaldi & Rasch (2020)

Conroy et al. (2006)

Creti et al. (2010) Crönlein et al. (2019)

South Africa Brazil

Canada

New Zealand Australia

20

77

88

47

145

China USA USA USA USA

United Kingdom Iceland Australia Brazil USA

Switzerland USA

USA USA USA

Taiwan USA

Korea Korea

USA

Korea Switzerland

USA

Canada Germany

Inpatients with schizophrenia

Healthy subjects undergoing in-lab sleep experiment Patients referred to a sleep centre

Firefighters Young adults

Individuals complaining of sleep-onset insomnia

15-year, then 17-year old students of the same cohort Professional rugby league athletes

School teachers Collegiate athletes

Patients with insomnia

Patients referred to a sleep centre for PSG Patients with multiple sclerosis

Individuals with fibromyalgia and Insomnia Community dwelling older adults with insomnia

Individuals with osteoarthritis

Patients referred to a sleep centre for an MSLT for suspected excessive daytime somnolence

Participants from the sleep heart health study

Patients referred to a sleep centre for PSG in addition to healthy volunteers

Cognitively normal and mildly impaired older adults

Outpatients with schizophrenia Young healthy students

Individuals experiencing insomnia in recovery from alcohol dependence

Participants with chronic fatigue syndrome Patients receiving CBT-I for insomnia

148

44

312

24

12

34

144

63

163

121

249

405

49

223

62

30

147

2540

420

293

66

24

21

49

92

34

Table 5: Characteristics of included studies *(continued)*

Study

Country of origin

Sample characteristics

Sample size

Currie et al. (2004)

Curtis et al. (2019) D’Aoust et al. (2015) Dautovich et al. (2008) De Francesco et al. (2021)

De Jaeger et al. (2019)

Dean et al. (2019) Devine et al. (2020) Dietch & Taylor (2021) Dinapoli et al. (2017)

Canada

USA USA USA

United Kingdom

Belgium

USA USA USA

Italy

Individuals experiencing insomnia in recovery from alcohol dependence

Participants with fibromyalgia and insomnia Informal caregivers of persons with dementia Older adults who nap habitually

People with HIV and people without HIV matched on demographic variables

Failed back surgery syndrome (FBSS) patients treated with spinal cord stimulation

Adults with inoperable non-small cell lung cancer Army Reserve Oﬀicers’ Training Corp Cadets Representative community-based normative sample

Older adults with mild cognitive impairment and subsyndromal depression

Chronic primary insomnia patients Commercial passenger airline pilots Undergraduate students

Subjective insomniacs

Patients undergoing PSG for suspected sleep-disordered breathing

Individuals with sleep disorders and contrls Judo athletes

Older adults with insomnia

Outpatients with insomnia presenting to a sleep disorders centre Individuals with insomnia

56

199

53

100

461

19

26

286

80

59

Dittoni et al. (2013) Dorrian et al. (2012) Dorsey & Bootzin (1997) Downey & Bonnet (1992) Duarte et al. (2020)

Italy Australia USA USA

Brazil

66

306

31

10

727

Duarte et al. (2022) Dunican et al. (2017) Dzierzewski et al. (2019) Edinger & Fins (1995) Espie et al. (1989)

Brazil Australia USA USA

United Kingdom

France USA

Germany Germany United Kingdom

USA

USA

Sweden

Germany

2004

23

159

173

20

Etain et al. (2021) Facco et al. (2018) Feige et al. (2008) Feige et al. (2021) Feng & Svetnik (2018)

Adults with bipolar disorder and healthy controls

Nulliparous women enrolled in the first trimester of pregnancy Individuals with paradoxical insomnia and good sleeper controls Insomnia patients and good sleeper controls

Primary insomnia patients

154

752

200

100

n/a

Fernandez-Mendoza et al. (2011)

Finan et al. (2020) Franklin & Svanborg (2000)

Friedmann et al. (2022)

Insomniacs and controls

Participants with opioid use disorder

Individuals referred to sleep center for suspected OSA

Women with PTSD after childhood abuse, mentally healthy women with a history of child abuse, and nontraumatised mentally healthy women

Healthy junior high school children

War veterans diagnosed with chronic PTSD Australian army recruits

Women recruited from the community Individuals with bipolar type I

Older adults with and without insomnia complaint

Patients with failed back surgery syndrome treated with spinal chord stimulation

Healthy males with normal sleep randomised to three experimental groups

Adolescents

Young adults in Munich

Women with PTSD secondary to interpersonal violence

Prostate cancer patients undergoing androgen therapy

Adults participants subject to COVID-19 lockdown provisions in China

866

55

100

184

Gaina et al. (2004)

Ghadami et al. (2015) Gibson et al. (2022) Girschik et al. (2012) Gonzalez et al. (2013) Gooneratne et al. (2011)

Goudman et al. (2018) Goulart et al. (2014)

Guedes et al. (2016) Gökce et al. (2020) Hall et al. (2022)

Hanisch et al. (2011) He et al. (2021)

Japan

Iran Australia Australia USA USA

Belgium Brazil

Brazil Germany USA

USA

China

42

32

59

56

39

200

39

31

37

74

45

60

70

35

Table 5: Characteristics of included studies *(continued)*

Study

Country of origin

Sample characteristics

Sample size

Heath et al. (2018) Herbert et al. (2017)

Hermans et al. (2019)

Hermans et al. (2020) Hermans et al. (2020) Hermans et al. (2021)

Herring et al. (2013) Hita-Yañez et al. (2013)

Hodges et al. (2017) Hoogerhoud et al. (2015)

Hsiao et al. (2018) Huang et al. (2012) Hughes et al. (2018)

Australia United Kingdom Netherlands

Netherlands Netherlands Netherlands

USA

Spain USA

Netherlands

Taiwan China USA

Adolescents

Individuals with insomnia symptoms

Older adults with and without insomnia Insomnia patients and healthy controls

Participants with insomnia on a waitlist for CBT-I

Older adults involved in a double-blind crossover study with zopiclone and placebo

Urban low-income pregnant women Patients with MCI and healthy elderly

Cocaine-dependent persons admitted to an inpatient research facility

Patients receiving index or maintenance ECT for a depressive episode

Healthy young adults

Primary insomnia patients and healthy controls Vulnerable older adults participating in a Veterans Administration Adult Day Health Care (ADHC) program

Patients with interstitial lung disease

Individuals with bipolar disorder and healthy controls

Women working at University College London and neighbouring institutions

Adults enrolled in a large longitudinal study African-American adults

Insomnia patients

Community-dwelling adults

Individuals with major depressive disorder, individuals with primary insomnia, and normal sleeping controls

Individuals with bipolar disorder and age and sex-matched controls

Individuals with bopolar disorder and healthy controls

Healthy university students

Older adults with and without sleep complaint Older adults with and without insomnia

Individuals with paradoxical insomnia and good sleeper controls Individuals involved in a study of early morning work or a study of sleep in a truck-berth

Patients with advanced chronic kidney disease or end-stage kidney disease

Community dwelling older adults with and without mild Alzheimers disease

Female undergraduates enrolled in an interior design programme Outpatients with primary insomnia undergoing CBT-I

Urban-residing African Americans with and without trauma exposure and PTSD

German undergraduate and graduate physical education students

Children recruited from primary and secondary schools in Hong King

Psychiatric inpatients

Breast cancer patients starting neoadjuvant chemotherapy Bipolar disorder patients and healthy controls similar in age, race, and sex

Patients with chronic insomnia

385

42

41

231

31

46

80

50

43

12

36

170

59

Hur et al. (2020) Ihler et al. (2020)

Jackowska et al. (2011)

Jackson et al. (2018) Jackson et al. (2019)

Janků et al. (2020)

Jungquist et al. (2016) Kang et al. (2018)

Kaplan et al. (2012)

Kaufmann et al. (2019) Kawada (2008)

Kay et al. (2013) Kay et al. (2015) Kay et al. (2017) Keklund & Akerstedt (1997)

Kennedy et al. (2020)

Khou et al. (2018)

King et al. (2017) Kishikawa et al. (2021) Kobayashi et al. (2012)

Canada France, Norway United Kingdom USA USA

Czech Republic USA USA

USA USA

Japan USA USA USA

Sweden

111

196

179

1910

821

36

300

82

54

85

76

103

114

62

37

Ireland

USA USA

Japan USA

54

86

28

52

103

Kolling et al. (2016) Kong et al. (2011)

Krahn et al. (1997) Kreutz et al. (2021) Krishnamurthy et al. (2018)

Kryger et al. (1991)

Germany China

USA

Germany USA

72

133

30

54

54

Canada

16

36

Table 5: Characteristics of included studies *(continued)*

Study

Country of origin

Sample characteristics

Sample size

Krystal & Edinger (2010)

Krystal et al. (2002)

Kundu et al. Kung et al. (2015)

Lan Chun Yang et al. (2021)

Laranjeira et al. (2018) Lastella et al. (2018) Lauderdale et al. (2008)

Lecci et al. (2020)

Lecci et al. (2020) (study 2)

Lee (2021)

Lee et al. (2021) Lee et al. (2022) Lehrer et al. (2022)

Lewis (1969)

Lipinska & Thomas (2017)

Liu et al. (2019) Liu et al. (2020)

Locihova et al. (2020)

USA USA

India Taiwan

Canada

Brazil Australia USA

Switzerland Switzerland

United Kingdom Korea Korea USA

United Kingdom South Africa

China China Czech Republic

United Kingdom USA

USA USA

Belgium

Patients with primary insomnia with sleep maintenance diﬀiculty evident in subjective sleep measures

Individuals with subjective insomnia, objective insomnia and normal controls

Individuals with chronic insomnia and obstructive sleep apnoea Taiwanese adults with major depression

Participants diagnosed with mTBI/concussion

Individuals referred to a sleep centre Well-trained male soccer players

Young adults enrolled in the Coronary Artery Risk Development in Young Adults study

Population-based sample

Insomnia patients and healthy subjects Adults aged 20 or above

Adults with insomnia Patients with OSA

Middle-aged community-dwelling women

Healthy young men

Women with PTSD, trauma exposure with no PTSD, and healthy controls

Healthy young adults Patients diagnosed with OSA

Patients admitted to an intensive care unit of a hospital

30

50

32

30

37

248

12

647

2092

34

8438

105

707

323

8

60

10

355

20

Lockley et al. (1999) Lubas et al. (2022)

Lund et al. (2013) Ma et al. (2021)

Maes et al. (2014)

Blind individuals

Participants enrolled in a longitudinal study of survivors of childhood cancer

Older adults with comorbid insomnia

Individuals with insomnia, insomnia & comorbid OSA, OSA only, and normal sleep controls

Female patients diagnosed with primary insomnia and healthy female controls

Individuals with insomnia and good sleeper controls Individuals with chronic fatigue and non-fatigued controls Normal subjects

159 patients with primary insomnia

Healthy right-hand males

Patients referred to a university-aﬀiliated sleep clinic for PSG Patients with minor depression, complaining of insomnia

Children aged 8-9 years recruited from elementary schools Patients diagnosed with current major depressive episode and chronic insomnia

Individuals undergoing PSG for suspected sleep apnoea

Healthy women late in third trimester

Middle-aged and older individuals with insomnia and matched normal sleepers

Participants who complained of poor sleep

Individuals with insomnia and age and sex matched controls Individuals with insomnia and good sleepers

49

477

60

638

28

Maich et al. (2018) Majer et al. (2007) Manconi et al. (2010) Manconi et al. (2010) (study 2)

Maric et al. (2019)

Martinez et al. (2010) Matousek et al. (2004)

Mazza et al. (2020) McCall & McCall (2012)

McCall et al. (1995) McIntyre et al. (2016)

Means et al. (2003)

Mendelson (1998) Mendelson et al. (1986) Mercer et al. (2002)

Canada USA

Italy, USA Italy

Switzerland

Brazil Czech Republic France USA

USA

New Zealand USA

USA USA USA

74

75

288

159

14

5764

28

76

54

84

30

101

8

20

22

37

Table 5: Characteristics of included studies *(continued)*

Study

Country of origin

Sample characteristics

Sample size

Meyer et al. (2018)

Miner et al. (2022) Moore et al. (2015)

Most et al. (2012) Mundt et al. (2016)

United Kingdom USA USA

Netherlands USA

Outpatients with schizophrenia

Community-dwelling older adults

43 women with insomnia who had completed treatment for breast cancer

Older adults with early and late stage alzheimers disease or healthy controls

Adults with insomnia and fibromyalgia randomised to CBT-I, CBT for pain, or waitlist control

Patients referred to a sleep clinic for evaluation of snoring/OSA Participants with subjective sleep diﬀiculty

Male veterans with traumatic brain injury Individuals with chronic fatigue and female controls

Older adults referred for insomnia complaints or suspected sleep apnoea

Paradoxical insomnia, psychophysiological insomnia, good sleepers

Treatment-seeking overwieght/obese participants Patients with fibromyalgia

Pregnant women

Female primary caregivers of children with disabilities

Patients with mild to severe traumatic brain injury and healthy good sleepers

Postmenopausal women Female fibromyalgia patients

Individuals with primary insomnia, insomnia secondary to depression, and good sleeper controls

Individuals selected from a university sleep laboratory

Individuals with psychophysiological insomnia, paradoxical insomnia, and good sleepers

Patients with insomnia, sleep-related movement disorders (SMD), hypersomnia, and parasomnia

Healthy, postmenopausal women having hot flash activity Adolescents diagnosted with delayed sleep-wake phase disorder Euthymic outpatients with bipolar disorder and healthy volunteers

Patients with narcolepsy and matched controls Adult patients referred to a clinical sleep laboratory Participants in a longitudinal study

Patients experiencing psychophysiological insomnia Community-dwelling older adults

Participants with primary insomnia

Sri Lankan adults

Individuals referred to a sleep centre for investigation of sleep disorders

Women with fibromyalgia and healthy controls

Patients in a methadone maintenance therapy for opioid dependence

Healthy sleepers

Adolescents Flight crew

Participants over 40

Patients with traumatic brain injury and non-injured controls

14

5835

43

81

113

Nam et al. (2016) Narisawa et al. (2015) Nazem et al. (2016) Neu et al. (2007) Nguyen-Michel et al. (2015)

Normand et al. (2016)

O’Brien et al. (2016) Okifuji & Hare (2011) Okun et al. (2021) Orta et al. (2016)

Ouellet & Morin (2006)

Park et al. (2007) Perlis et al. (1997) Perlis et al. (2001)

Pinto Jr et al. (2009) Provencher et al. (2020)

Reess et al. (2010)

Regestein et al. (2004) Richardson et al. (2019) Ritter et al. (2016)

Korea Japan USA

Belgium France

50

50

19

40

135

Canada

USA USA USA

Chile

Canada

USA USA USA

Brazil Canada

Germany

USA

Australia Germany

70

63

75

104

175

28

384

20

27

199

67

159

88

103

50

Rogers et al. (1993) Saline et al. (2016) Santos et al. (2021) Sato et al. (2010) Scarlett et al. (2021)

Schneider-Helmert & Kumar (1995) Schokman et al. (2018) Schulz & Walther (2017)

Segura-Jimenez et al. (2015)

Sharkey et al. (2011)

USA USA

Brazil Japan Ireland

Switzerland

Sri Lanka Germany

Spain USA

50

643

2036

20

1520

128

175

117

198

62

Sharman et al. (2022)

Short et al. (2012) Signal et al. (2005) Silva et al. (2007) Sinclair et al. (2014)

United Kingdom Australia USA USA

Australia

16

385

21

2113

42

38

Table 5: Characteristics of included studies *(continued)*

Study

Country of origin

Sample characteristics

Sample size

Slightam et al. (2018) Smagula et al. (2021) So et al. (2021) Somma et al. (2020)

Spielmanns et al. (2019) Spinweber et al. (1985)

Sprajcer et al. (2020) St-Onge et al. (2019) Stout et al. (2017)

Sun-Suslow et al. (2022)

Takano et al. (2016) Tang & Harvey (2004)

Tang & Harvey (2004) (study 2)

Tang & Harvey (2006) Tang et al. (2007)

USA USA USA

Italy

Germany USA

Australia USA USA

USA

Belgium United Kingdom United Kingdom Various United Kingdom

United Kingdom Norway USA

Japan Various

Serbia, USA Australia Australia Austria

Austria Japan

Japan Switzerland Canada Netherlands

Veterans with PTSD and demographically similar controls Males

Prepubertal children

Participants with insomnia and community dwelling adults matched on demographic variables

CPAP users

Laboratory-qualified poor sleepers laboratory-disqualified poor sleepers who were male students at a naval school

Healthy adult male on-call workers

Multi-racial, multi-ethnic sample of adults

Military veterans and active-duty service members, 17 with PTSD, 20 without PTSD

People with and without HIV

Adults

Healthy good sleepers Healthy good sleepers

Individuals with primary insomnia Poor and good sleepers

120

2850

55

60

26

60

72

113

37

94

54

54

93

48

60

Tang et al. (2007) (study 2)

Thun et al. (2012) Thurman et al. (2018) Tomita et al. (2013) Topalidis et al. (2021)

Trajanovic et al. (2007) Tremaine et al. (2010) Tremaine et al. (2010) Trimmel et al. (2021)

Trimmel et al. (2021) Tsuchiyama et al. (2003)

Usui et al. (2003) Valko et al. (2021)

Vallieres & Morin (2003) Van Den Berg et al. (2008)

Vanable et al. (2000) Wang et al. (2011) Wang et al. (2022) Werner et al. (2016)

Williams et al. (2011) Wilson et al. (1998)

Wilson et al. (2013)

Winer et al. (2021) Wolfson et al. (2003) Xu et al. (2022)

Yamakita et al. (2014) Yeung et al. (2015) Yoon et al. (2022)

Patients with primary insomnia split into a clock-monitoring group and display unit-monitoring group

University students Healthy participants

patients complaining of excessive daytime sleepiness Healthy participants

Patients referred to a sleep clinic Children and adolescents Children aged 11-16

Patients with a range of sleep disorders who underwent laboratory or ambulatory PSG

Patients referred to sleep clinic in a department of neurology

Patients with major depression admitted to a psychiatric hospital

Older and younger adults

Patients referred to a sleep clinic for PSG Participants with chronic primary insomnia Community-dwelling older adults

38

166

30

28

21

136

66

65

303

303

23

39

3303

17

969

USA

Taiwan Canada USA

USA

Canada Australia

USA USA

China

Japan China Korea

Patients referred to sleep clinic with various sleep disorders Heart failure patients

Naval sailors

Women with PTSD experiencing PTSD-related sleep disturbance

Community-dwelling older adults

Individuals experiencing insomnia associated with chronic musculoskeletal pain

Women in third trimester and first trimester of pregnancy and non-pregnant women

Cognitively normal older adults High school students

Young adults

School-aged children

Individuals with insomnia undergoing placebo acupuncture Patients with insomnia

104

43

66

51

142

40

64

89

302

47

58

86

150

39

Table 5: Characteristics of included studies *(continued)*

Study

Country of origin

Sample characteristics

Sample size

Zak et al. (2022) Zhu et al. (2018)

Zinkhan et al. (2014) Zou et al. (2021)

te Lindert et al. (2020)

USA USA

Germany China Netherlands

Healthy premenopausal women Adults with type II diabetes

Participants recruited from the community

Insomnia disorder patients and well-matched healthy controls Individuals with insomnia disorder and individuals without sleep complaints

71

53

100

64

236

40

Full qualitative methodological details for actigraphy studies are available in Table [6](#_bookmark29).

Table 6: Qualitative actigraphy characteristics

Study

Actigraph device

Software

Algorithm

Algorithm reference

Rest interval definition

1

3

4

Chou et al. (2020)

Janků et al. (2020)

King et al. (2017)

Lehrer et al. (2022)

Segura- Jimenez et al. (2015)

Slightam et al. (2018)

Williams et al. (2011)

Al Lawati et al. (2021)

Ansok et al. (2020)

Auger et al. (2013)

Baillet et al. (2016)

Billings (2020)

Brychta et al. (2019)

Cederberg et al. (2022)

Chan et al. (2018)

Actiwatch 2

MotionWatch 8

Actiwatch Spectrum Plus Actiwatch AW64

SenseWear Pro3 Armband

Actiwatch AW64

Actiwatch-L

Actiware

MotionWare not reported

Actiware Low (20)

MotionWare

Actiware Medium (40)

Actiware Medium (40)

SenseWear

Boyne et al. (2013)

CamNTech, UK

Boyne et al. (2013)

Boyne et al. (2013)

Lopez et al. (2017)

Not reported

Event marker –> sleep diary

Not reported

5

Actiware

Informed by sleep diaries, decided by study staff

Set intervals

7

SenseWear Professional

8

Actiware

Actiware Medium (40)

Actiware (not reported) Domino Light

Cole-Kripke

Boyne et al. (2013)

Boyne et al. (2013)

Gorny et al. (1996)

Cole et al. (1992)

Kripke et al. (1978)

CamNTech, UK

Cole et al. (1992)

Sadeh et al. (1994)

Cole et al. (1992)

Event markers –> activity, sleep diary

Not reported

10

Actiware- Sleep

Domino Light

not reported

11

12

SOMNOwatch plus Actiwatch Spectrum Plus Actiwatch

AW64

MotionWatch 8

ActiGraph wGT3X-BT

ActiGraph GT3X+

ActiGraph GT3X+

Actiwatch 2

Manual scoring

Event markers –> sleep diary

Automated –> sleep diary

Event markers –> sleep diary

Sleep diary, inconsistenies reviewed with participant Visual inspection, sleep diaries

Sleep diary

Complex criteria involving sleep diary, activity levels, light

Event marker

Event markers –> sleep diaries –> activity/light patterns

Not reported

Not reported

14

Actiware

Kripke

15

18

19

20

21

MotionWare ActiLife ActiLife ActiLife

not reported

MotionWare Cole-Kripke Sadeh

Cole-Kripke

not reported

25

26

Currie et al. (2004)

Dietch & Taylor (2021)

Dunican et al. (2017)

Facco et al. (2018)

Ghadami et al. (2015)

Girschik et al. (2012)

Herring et al. (2013)

Mini Motion- logger Actiwatch Spectrum

not reported not reported

not reported

Actiware

Cole-Kripke

Actiware Low (10)

not reported

Actiware Medium (40)

not reported

Cole et al. (1992)

Boyne et al. (2013)

28

29

Readiband Sync

not reported

Boyne et al. (2013)

32

not reported

not reported

Not reported

33

Actiwatch Spectrum

Actiwatch AW64

Actiware

Actiware Medium (40)

Actiware (not reported)

Boyne et al. (2013)

Boyne et al. (2013)

Event marker –> sleep diary

Event markers –> sleep diary

36

Actiware

41

Table 6: Qualitative actigraphy characteristics *(continued)*

Study

Actigraph device

Software

Algorithm

Algorithm reference

Rest interval definition

37

Hoogerhoud et al. (2015)

Ihler et al. (2020)

not reported

not reported

Actiware (not reported) Actiware (not reported)

Actiheart

Boyne et al. (2013)

Boyne et al. (2013)

Not reported

38

Actiwatch AW7

Actiwatch activity & sleep analysis Actiheart

Event markers

39

Jackowska et al. (2011)

Kaplan et al. (2012)

Actiheart monitor

Actiwatch AW64

Barreira et al. (2009)

Boyne et al. (2013)

Sleep logs; heart rate; activity

Set to lights off and lights-on from PSG

41

Actiware

Actiware (Low, Medium, High) Actiware Medium (40)

Actiware Medium (40),

Cole-Kripke Actiware High (80) Cole-Kripke

42

Kawada (2008)

Kay et al. (2015)

Actiwatch

not reported

Boyne et al. (2013)

Boyne et al. (2013); Cole

et al. (1992)

Boyne et al. (2013)

Cole et al. (1992)

Not reported

43

Actiwatch 2

Actiware

Event marker; sleep diary; activity; light

44

47

Kay et al. (2013)

Khou et al. (2018)

Actiwatch-L

ActiGraph GT3X+

not reported

ActiLife

Not reported

Self-report sleep logs 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

Not reported

Scored manually (tech was blinded to sleep diary)

Automatic (heart rate + activity)

Sleep diaries

48

49

Kong et al. (2011)

Krahn et al. (1997)

Liu et al. (2019)

Lockley et al. (1999)

Mazza et al. (2020)

not reported

not reported

not reported

not reported

not reported

Cole-Kripke

Cole et al. (1992)

Haghayegh et al. (2019)

52

53

Fitbit Alta

Motionlogger, Mini Motion- logger Actiwatch 2

Fitbit software Action 3

Fitbit

not reported

58

Actiware

Actiware Medium (40)

Actiware Medium (40)

Actiware (not reported) Actiware High (80) Actiware (not reported) not reported

Boyne et al. (2013)

Event marker, activity, light

61

Moore et al. (2015)

Most et al. (2012)

Mundt et al. (2016)

Nazem et al. (2016)

Okifuji & Hare (2011)

Actiwatch 2

Actiware

Boyne et al. (2013)

Boyne et al. (2013)

Boyne et al. (2013)

Boyne et al. (2013)

Not reported

62

Actiwatch

Actiware

Vinyl-covered pressure sensitive pad and

light-dependent resistor Sleep diaries

Not reported

63

65

Actiwatch 2

Actiwatch 2

Actiware

Actiware

67

Micro Mini Motionlog- ger

Action

Not reported

42

Table 6: Qualitative actigraphy characteristics *(continued)*

Study

Actigraph device

Software

Algorithm

Algorithm reference

Rest interval definition

68

71

Orta et al. (2016)

Regestein et al. (2004)

Ritter et al. (2016)

Sato et al. (2010)

Sharman et al. (2022)

ActiSleep

not reported

ActiLife

not reported

Cole-Kripke

Actiware Medium (40)

Cole-Kripke

Cole-Kripke

Actiware Medium (40)

Cole et al. (1992)

Boyne et al. (2013)

Cole et al. (1992)

Cole et al. (1992)

Boyne et al. (2013)

Not reported

Sleep diary

72

74

76

SOMNOWatch Plus

not reported

Actiwatch AW4

Domino Light

not reported

Actiwatch Activity and Sleep Analysis

not reported Action 4 Action W ActiLife

not reported

Event markers Not reported

Event markers –> sleep diary, verification from audio file timestamps

78

82

83

87

90

Spielmanns et al. (2019) Wang et al. (2022)

Werner et al. (2016)

Barbosa et al. (2017)

Broomfield & Espie (2003)

Caia et al. (2018)

PAM Polar A300

Micro Mo- tionlogger not reported

ActiGraph GT3X+

Actiwatch 2

not reported not reported UCSD

Cole-Kripke

not reported

n/a

Event markers Automatic

Sleep diary, activity, light

Event markers

Jean-Louis et al. (2001) Cole et al. (1992)

91

Actiwatch 2, ActiGraph GT3X+,

Readiband Actiwatch 2

not reported

not reported

Not reported

92

Campanini et al. (2017)

Carter et al. (2020)

Chung et al. (2020)

Dautovich et al. (2008)

Actiware

Actiware Medium (40)

Actiware Medium (40)

Actiware Medium (40)

Actiware High (80)

Boyne et al. (2013)

Boyne et al. (2013)

Boyne et al. (2013)

Boyne et al. (2013)

Algorithms supplemented by event marker

Light

93

Actiwatch Spectrum Pro Actiwatch 2

not reported

97

Actiware

Event marker or sleep diary

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

Not reported

98

Actiwatch-L

Actiware- Sleep

99

De Jaeger et al. (2019)

Dean et al. (2019)

Gonzalez et al. (2013)

Goudman et al. (2018)

Hanisch et al. (2011)

Actiwatch Spectrum Plus Octagonal Sleep Watch Motionlogger

Actiwatch Spectrum Plus Actiwatch AW64

Actiware

Actiware (not reported) not reported

UCSD

Actiware (not reported) Actiware (not reported)

Actiware Medium (40)

Boyne et al. (2013)

100

104

105

Action 3 Action

Actiware

Sleep diary Not reported

Not reported

Jean-Louis et al. (2001) Boyne et al. (2013)

Boyne et al. (2013)

107

Actiware- Sleep

Sleep diary

111

Hughes et al. (2018)

Actiwatch Spectrum

not reported

Boyne et al. (2013)

Not reported

43

Table 6: Qualitative actigraphy characteristics *(continued)*

Study

Actigraph device

Software

Algorithm

Algorithm reference

Rest interval definition

112

113

Kaufmann et al. (2019) Kreutz et al. (2021)

Actisleep- BT

ActiGraph wGT3X-BT

not reported

ActiLife

not reported

Cole-Kripke, Tudor-Locke

Not reported

Tudor-Locke algorithm

Cole et al. (1992);

Tudor-Locke et al. (2014) Peach et al. (2014)

114

118

Krishnamurthy not reported et al. (2018)

ActiLife

not reported

ActiLife

not reported

Not reported

Event markers –> sleep log

Event markers

Not reported

Lauderdale et al. (2008)

Lubas et al. (2022)

Maich et al. (2018)

Okun et al. (2021)

Park et al. (2007)

Scarlett et al. (2021)

Actiwatch AW16

Motionlogger

Actiwatch Score

Actiwatch

119

120

not reported

Mini-Mitter Actiwatch Software Actiware

not reported

Actiware Low (20)

Actiware Medium (40)

Actillume

Micro- Electro- Mechanical Systems

Actiware Medium (40)

Boyne et al. (2013)

Boyne et al. (2013)

Jean-Louis et al. (2001) Dunne et al. (2013)

126

Autointerval option with event markers

Sleep diary, notes, light,

Webster’s rules n/a

127

131

Actillume I

GENEactiv

Actillume Algorithm GENEactive

132

Schokman et al. (2018)

Actiwatch Spectrum Pro

Actiware

Boyne et al. (2013)

Manual: visual inspection, sleep diary entry, Actiwatch timestamps (according to neurosleep manual)

Not reported

Defined in-lab

133

134

Stout et al. (2017)

Tang & Harvey (2004)

Thun et al. (2012)

Micro Sleep Watch

Mini Motion- logger Basic

not reported

not reported

not reported

Cole-Kripke, Webster’s rescoring rules Actiware Medium

(40)

not reported

Cole et al. (1992)

135

Actiwatch AW7

Actiwatch Activity and Sleep Analysis Action W2

Boyne et al. (2013)

Not reported

136

Tomita et al. (2013)

Tremaine et al. (2010)

Usui et al. (2003)

Wilson et al. (1998)

MicroMini RC

not reported

Manually corrected, using diaries where necessary

Not reported

137

Actiware-

Sleep

not reported not reported

Actiware Medium (40)

Cole-Kripke

Cole-Kripke, Webster’s rescoring rules

Sadeh

Sleep Sign Act

Boyne et al. (2013)

Cole et al. (1992)

Cole et al. (1992)

139

142

Motionlogger

Mini Motion- logger

n/a

Not reported

143

144

Wolfson et al. (2003)

Yamakita et al. (2014)

Mini Motion- logger Lifecorder

Action W2

Sleep Sign Act

Sadeh et al. (1994)

Kissei Comtec Co, Japan

Boyne et al. (2013)

Sleep diary

Set manually

145

Yeung et al. (2015)

Actiwatch 2

Actiware, Action W

Actiware (not reported)

Not reported

44

Table 6: Qualitative actigraphy characteristics *(continued)*

Study

Actigraph device

Software

Algorithm

Algorithm reference

Rest interval definition

148

Baek et al. (2020)

Chan et al. (2021)

Chen et al. (2015)

Heath et al. (2018)

Actiwatch Spectrum Pro Actiwatch-L

Actiware

Actiware Medium (40)

Actiware Medium (40)

not reported

Sadeh

Boyne et al. (2013)

Boyne et al. (2013)

Sleep diary

149

Actiware-

Sleep

not reported Action W2

Sleep diary

150

154

not reported

Micro Mini Motionlog- ger

Mini Motion- logger Actiwatch AW64

IM Systems Actigraph

Not reported

Not reported

Sadeh et al. (1994)

156

157

Kobayashi et al. (2012)

McCall & McCall (2012)

Vallieres & Morin (2003)

Zhu et al. (2018)

Action W2

Actiware

Sadeh

Actiware Medium (40)

IM Systems

Sadeh et al. (1994)

Boyne et al. (2013)

Individual Monitoring Systems, Inc., USA

Boyne et al. (2013); Cole

et al. (1992)

Jean-Louis et al. (2001)

Lopez et al. (2017)

Cole et al. (1992)

Sadeh et al. (1994)

Boyne et al. (2013)

Lopez et al. (2017)

Sleep diary, habitual sleep questionnaire Not reported

159

Individual Monitoring Systems

ActiLife

Not reported

160

ActiGraph wGT3X

Actiware Medium (40),

Cole-Kripke UCSD

Not reported

161

Hall et al. (2022)

Kolling et al. (2016)

Locihova et al. (2020)

Winer et al. (2021)

D’Aoust et al. (2015)

Dinapoli et al. (2017)

Motionlogger Basic

SenseWear MF

Armband ActiGraph wGT3X-BT

Micro Mo- tionlogger Actiwatch-L

Action W

n/a

163

SenseWear Professional

ActiLife Action W2 Actiware

SenseWear

Event marker –> activity

164

167

168

Cole-Kripke Sadeh

Actiware (not reported) SenseWear

Externally defined

Sleep diary and event markers

Sleep diary

169

SenseWear MF

Armband

not reported

SenseWear

Not reported

170

Dorrian et al. (2012)

O’Brien et al. (2016)

St-Onge et al. (2019)

Arora et al. (2013)

Curtis et al. (2019)

Actiware- Sleep

Action W not reported not reported Actiware

Actiware Medium (40)

Sadeh

not reported not reported

Actiware (not reported)

Actiware Medium (40)

Actiware (not reported)

Boyne et al. (2013)

Sadeh et al. (1994)

Not reported

173

174

176

180

Motionlogger Basic ActiGraph GT3X+

ActiGraph GT3X+

Actiwatch 2

Sleep diary, discrepancies queried

Not reported

Sleep diary Sleep diary

Boyne et al. (2013)

181

Devine et al. (2020)

Dzierzewski et al. (2019)

Actiwatch 2

Actiware

Boyne et al. (2013)

Boyne et al. (2013)

Automatically defined, sleep diary/ other daily schedule info

Not reported

183

Actiwatch Spectrum

not reported

45

Table 6: Qualitative actigraphy characteristics *(continued)*

Study

Actigraph device

Software

Algorithm

Algorithm reference

Rest interval definition

184

Etain et al. (2021)

Actiwatch AW7

Actiwatch Activity and Sleep Analysis ActiLife

Actiware

Actiware (not reported)

Cole-Kripke Cole-Kripke

Boyne et al. (2013)

Sleep diary and event markers

186

187

Gibson et al. (2022)

Gökce et al. (2020)

Herbert et al. (2017)

Jackson et al. (2018)

Kung et al. (2015)

Lee (2021)

ActiGraph GT9X Link ActiGraph wGT3X-BT

MotionWatch 8

Actiwatch Spectrum

Mini Motion- logger

ActiGraph GT3X+

Fitbit Charge HR

Actiwatch 2

Cole et al. (1992)

Cole et al. (1992)

Sadeh et al. (1994)

Boyne et al. (2013)

Externally defined (platoon sleep record) Software-defined

188

191

MotionWare

Actiware- Sleep

Action W2

Sadeh

Actiware (not reported) not reported

Sleep diary

Event marker, sleep diary, light sensor

Externally-defined (lights on/off times at psychiatric ward)

Not reported

193

196

not reported

Machine learning algorithm Fitbit

John et al. ( 2019)

Haghayegh et al. (2019)

Boyne et al. (2013); Cole

et al. (1992)

199

Meyer et al. (2018)

Kishikawa et al. (2021)

Sleepsight

n/a

200

Actiware

Actiware Medium (40),

Cole-Kripke not reported

Cole-Kripke, UCSD

Event markers

201

203

Santos et al. (2021)

Smagula et al. (2021)

Actiwatch 2

SleepWatch- O

not reported

Action W2

Event marker

Sleep diary –> manual scoring

Cole et al. (1992);

Jean-Louis et al. (2001) Boyne et al. (2013)

204

te Lindert et al. (2020)

GENEactiv

GENEactive

Actiware (Low, Medium, High) Fatigue Science

Sleep diary

205

Thurman et al. (2018)

Readiband Actigraph SBV2

Xiaomi Mi Band 3, GT3X

ActiGraph Actiwatch AW4

Mini Motion- logger, Actigraph Model

AAM-32

ActiGraph wGT3X-BT

Actiwatch

Fatigue Science Software

ActiLife

Russel et al. (2016)

Sleep offset/onset defined by sleep state

(9pm-11am)

n/a

206

Topalidis et al. (2021)

Cole-Kripke

Cole et al. (1992)

207

Van Den Berg et al. (2008)

Zak et al. (2022)

Actiware

Actiware Low (20)

Cole-Kripke

Boyne et al. (2013)

Cole et al. (1992)

Event marker –> sleep diary

Event marker

208

Action

209

De Francesco et al. (2021)

Gaina et al. (2004)

Guedes et al. (2016)

not reported

not reported

Not reported

210

not reported

not reported

Sleep diary

211

Mini Motion- logger Basic

Action W2

Sadeh

Sadeh et al. (1994)

Sleep/activity log

46

Table 6: Qualitative actigraphy characteristics *(continued)*

Study

Actigraph device

Software

Algorithm

Algorithm reference

Rest interval definition

213

Sinclair et al. (2014)

Takano et al. (2016)

Tang et al. (2007)

Tang & Harvey (2006)

Wang et al. (2011)

Creti et al. (2010)

not reported

Actiware

Actiware Medium (40)

Cole-Kripke

Cole-Kripke

Boyne et al. (2013)

Cole et al. (1992)

Cole et al. (1992)

Cole et al. (1992)

Sleep diary

214

215

ActiGraph wGT3X-BT

Mini Motion- logger Basic

Mini Motion- logger Basic

Actiware

Action W

Unsure/ not reported

Webster’s rules (daily sleep logs, notes, illumination channel) Webster’s rules (daily sleep logs, notes, illumination channel)

Not reported

Externally set (PSG)

216

Action W

Cole-Kripke

217

219

Motionlogger

Actitrac

Action W2

IM Systems Software

not reported

IM Systems

Individual Monitoring Systems, Inc., USA

Cole et al. (1992); Choi

et al. (2011); Troiano et al. (2007)

Cole et al. (1992)

CamNTech, UK

Sadeh et al. (1994)

Sadeh et al. (1994)

Cole et al. (1992)

Boyne et al. (2013)

Cole et al. (1992)

Boyne et al. (2013)

222

He et al. (2021)

ActiGraph wGT3X-BT

ActiLife

Cole-Kripke, Choi, Troiano

N/a or not reported

223

224

Hur et al. (2020)

Jungquist et al. (2016)

Short et al. (2012)

So et al. (2021)

Sun-Suslow et al. (2022) Tremaine et al. (2010)

Jackson et al. (2019)

Bean et al. (2021)

ActiGraph wGT3X-BT

Camntech Pro-Diary

Motionlogger

Micro Mo- tionlogger ActiGraph GT9X Link not reported

ActiLife

MotionWare

Cole-Kripke

MotionWare

Sleep diaries

Not reported

230

231

233

234

Action W2 not reported not reported

Actiware- Sleep

ActiLife

Sadeh Sadeh

Cole-Kripke

Actiware Medium (40)

Cole-Kripke

Sleep diary Event marker

Sleep diary –> manual

Sleep diary

235

ActiGraph GT3X+

Actiwatch AW64

Manual: sleep diary, activity, light

Sleep diary

237

Cambridge Neurotech- nology Sleep Analysis 5.5 Action W2

not reported

Actiware (not reported)

UCSD

Sadeh

238

239

Miner et al. (2022)

Richardson et al. (2019)

Friedmann et al. (2022) Signal et al. (2005)

SleepWatch- O

Micro Mini Motionlog- ger

Move II

Actiwatch

Jean-Louis et al. (2001) Sadeh et al. (1994)

Barouni et al. (2020)

Boyne et al. (2013)

Software and sleep diaries

Manual and sleep diary

241

243

not reported

Actiware- Sleep

Barouni

Actiware (Low, Medium, High)

not reported

Cole-Kripke

Sleep onset during fixed interval: 20:00-00:00 Event marker, sleep diary

244

245

Narisawa et al. (2015)

Tang & Harvey (2004)

(study 2)

Actiwatch

Mini Motion- logger Basic

not reported

not reported

Activity levels

Defined in-lab

Cole et al. (1992)

47

Table 6: Qualitative actigraphy characteristics *(continued)*

Study

Actigraph Software device

Algorithm

Algorithm reference

Rest interval definition

248

Tang et al. (2007)

(study 2)

Mini Motion- Action W logger Basic

Cole-Kripke

Cole et al. (1992)

Webster’s rules (daily sleep logs, notes, 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.

48

A full list of studies that recorded sleep-wake agreement is available in Table [7](#_bookmark30) below.

Table 7: Direct sleep-wake agreement studies

Study

Sample characteristics

Sleep variables

Sleep-wake agreement type

PSG setting

60

Mendelson et al. (1986)

Rogers et al. (1993)

individuals with insomnia and age and sex matched controls

patients with narcolepsy and matched controls

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

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

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

sleep/ wake agreement, 10-minute epochs

SOL, participant sleep/wake judgement following experimental awakenings

Binary

in-lab

73

Confusion matrix

home-based

101

Dorsey & Bootzin (1997)

undergraduate students

Confusion matrix

in-lab

123

Mendelson (1998)

Mercer et al. (2002)

participants who complained of poor sleep

individuals with insomnia and good sleepers

Binary

in-lab

124

Binary

in-lab, home-based

139

152

Usui et al. (2003)

Downey & Bonnet (1992)

Nguyen- Michel et al. (2015)

Dorrian et al. (2012)

Schulz & Walther (2017)

older and younger adults

subjective insomniacs

Confusion matrix Binary

n/a

in-lab

165

older adults referred for

Perception of sleep during nap

Binary

in-lab

insomnia complaints or (binary)

suspected sleep apnoea commercial passenger airline pilots

individuals referred to a sleep centre for investigation of sleep disorders

170

229

TST; sleep/wake

sleep / wake judgement following induced awakenings

Confusion matrix Binary

n/a

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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