Approaches to Measuring and Conceptualising Sleep Discrepancy: A Scoping Review

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# 1 Abstract

## 1.1 Study Objectives

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

## 1.2 Method

We searched MEDLINE (Ovid), Embase (Ovid), PsycINFO (Ovid), CINAHL Plus, PubMed, Scopus, and Web of Science in April 2022 for relevant studies. Titles and abstracts, and then full text records of searched studies were screened. Methodological information was extracted including measures of self-report and objective sleep, sleep variables, derived discrepancy indices (e.g., difference scores), handling of repeated measurements, and methods of measure comparison (e.g., Bland-Altman analyses).

## 1.3 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.

## 1.4 Conclusions

Conceptually, sleep discrepancy was mostly restricted to discordance in sleep states and sleep time variables, and some forms of sleep discrepancy differ in their similarity to sleep misperception. Methodologically, approaches to sleep discrepancy varied considerably across areas of study design, measurement, data processing, and data analysis. This variability may exceed the size of effects looked for in relationships with other constructs and may pose difficulties in the pragmatics of research in this area. Additional issues are discussed relating to the use of derived indices for operationalising sleep discrepancy, objective sleep onset latency definitions, calculation of actigraphy rest intervals, differences between correlation and concordance, averaging of sleep variables across nights, the conceptual status of sleep quality discrepancy, and the scope of the sleep discrepancy literature.

## 1.5 Key words

Sleep discrepancy; sleep misperception; scoping review

# 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 measures1–3.

There are diverse ways to conceptualise and measure sleep discrepancy. It may be considered as a spectrum4, ranging from positive (self-report exceeds objective) to negative (objective exceeds self-report), or as a measure of absolute sleep agreement5. Any number of sleep variables such as TST, SOL, or WASO may used to operationalise sleep discrepancy, each differing conceptually and carrying varying theoretical implications. Sleep discrepancy may even be considered beyond these sleep time-based metrics and represent discordance in self-report and objective sleep patterns6, or sleep quality. Sleep discrepancy may be characterised in a sample by directly comparing self-report and objective sleep with a range of statistical techniques. Other studies may derive variables to define sleep discrepancy quantitatively to measure its relationship with other variables, for example using a difference score of self-report TST - objective TST. There appear to be a variety of ways to derive these variables each of which, again, are likely to hold varying conceptual implications.

To date, there have been few systematic attempts to synthesise or evaluate the varied approaches to investigating sleep discrepancy. Three reviews have been conducted in this area. Castelnovo et al7 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 al8 and Stephan et al9 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 and did not incorporate a systematic search—potentially under representing the breadth of the literature.

Presently, it is not clear how sleep discrepancy should best be defined and the diversity in its measurement and conceptualisation may present a challenge to theory-building for research in insomnia and other areas. 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 topic10. 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 two reviews mentioned above, no records were identified.

# 3 Methods

## 3.1 Protocol and registration

The review was conducted according to guidelines provided by the JBI scoping review methodology group11 and reported according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist12. 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).

## 3.2 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 composite index scores. For measures of self-report and objective sleep, we included traditional 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.

## 3.3 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) included self-report or objective measures that were not related to sleep, (v) contained no empirical data, (vi) omitted either a self-report or equivalent objective measure of sleep, or (vii) were a grey literature source including theses, dissertations, and conference abstracts. No records were excluded on the basis of geographic location, cultural factors, or any other contextual feature.

## 3.4 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 3.1 below. See Appendix A for full search strategies for other databases.

(#tab:egsearch)Search strategy for Embase (Ovid)

Step

Terms and Operators

Records

1

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

488

2

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

193243

3

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

1676

4

(sleep\* and (“over estimat*” or ”over report*” or “under estimat*” or ”under report*” or overestimat\* or overreport\* or underestimat\* or underreport\* or discrepan\* or concordan\* or agreement or disagreement or discordan\* or congruen\* or incongruen\*)).mp.

9362

5

2 or 3

193302

6

4 and 5

1234

7

1 or 6

1569

## 3.5 Sources of evidence selection

Records identified from searches were exported to EndNote 2013 for collation and then uploaded to Rayyan14 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 independently by TW with reasons for exclusion reported. Due to the unanticipated size of the literature, articles from sources other than peer-reviewed journals were added to exclusion criteria post-hoc.

## 3.6 Charting the data

Data extraction was performed by TW, independently. Methodological features of included articles were selected on their potential 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 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.

## 3.7 Data items

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

## 3.8 Synthesis of results

This manuscript, including all tables and figures summarising data were generated using computationally reproducible methods15,16 in R version 4.3.217, with R Studio18 and R Markdown19. Packages used in the code for this manuscript include tidyverse20, bookdown21, knitr22, kableExtra23, english24, and DiagrammeR25. All code and data are available through the github repository: <https://github.com/tfwalton/sleep-discrepancy-review>.

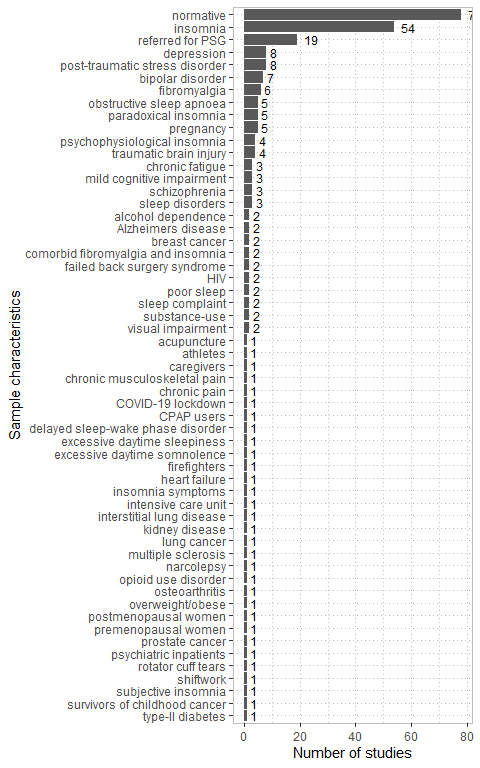
# 4 Results

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 4.1 below.

Figure 4.1: PRISMA flowchart

## 4.1 Article characteristics

A total of 248 studies were identified from (n = 244) records, with (n = 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 4.2. For a full list of article characteristics, see the appendices (11.4) 

## 4.2 Methodological features

### 4.2.1 Measures of objective sleep

Objective methods of recording sleep formed two major groups: EEG-based methods (n = 116) and movement-based methods (n = 143). 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 night26.

#### 4.2.1.1 Polysomnography

Methodological features charted for PSG included scoring criteria, setting, and recording period. Scoring criteria for PSG were split between American Academy of Sleep Medicine (AASM; n = 45) and Rechtschaffen & Kales (R&K; n = 56) guidelines. Rogers et al27 used an automated system for sleep staging, the SS90-III Sleep Stager System (Oxford Medicals, Oxford). Vanable et al28 used Mendelson’s29 guidelines in addition to R&K. Edinger2 used combined audio and visual criteria for sleep staging30. A total of 5 studies did not report scoring criteria. In terms of setting, PSG was more frequently conducted in a laboratory (n = 89) than at home (n = 21). Other environments included a truck-berth (n = 1), fMRI (n = 1) and an airline rest facility (n = 1). Two studies did not report scoring criteria. Recording periods were predominantly nocturnal (n = 99), but also included daytime naps (n = 5), and other sleep periods (n = 4).

#### 4.2.1.2 Actigraphy

We recorded features of actigraphy including device name, scoring algorithm, software, and rest interval definition. See Table 11.5 in the appendices for full tabulations of actigraphy characateristics. Actigraphy scoring algorithms are responsible for determining wakefulness and sleep from accelerometer-derived motor activity. Scoring algorithms varied across studies and included Actiware31, MotionWare (CamNTech, UK), SenseWear32, Domino Light33, Cole-Kripke34, Kripke35, Sadeh36, Actiheart37, Fitbit38, UCSD38, ActiLife39, Actillume38, Micro-Electro-Mechanical-Systems40, Sleep Sign Act (Kissei Comtec Co, Japan), IM Systems (Individual Monitoring Systems, Inc., UWA), Machine Learning Alogrithms41, Fatigue Science42, Barouni43, Choi44, Tudor-Locke45, and Troiano46. The frequencies of these algorithms are depicted in Figure 4.3.

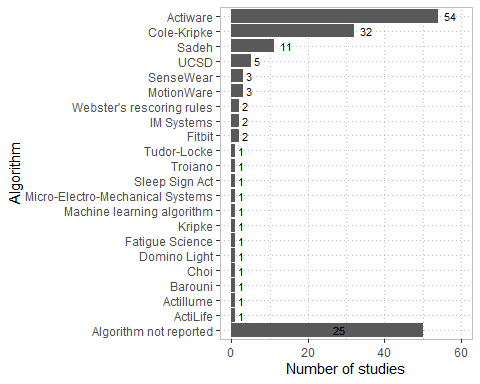


Figure 4.3: Actigraphy algorithms

Studies using Actiware algorithms varied in their selection of thresholds for scoring wakefulness. These are depicted in Figure 4.4 below.

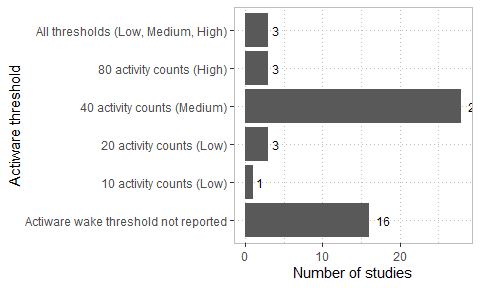


Figure 4.4: Actiware algorithm threshold settings

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 4.5.

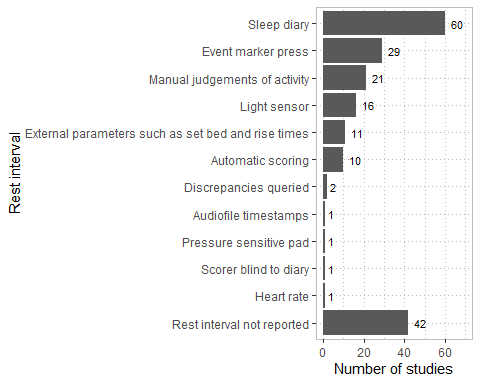


Figure 4.5: Methods for defining rest intervals in actigraphy

The precise combinations or orders of priority of methods in each study varied markedly. See Table 11.5 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

Nine types of self-report sleep measure were identified: sleep diaries such as the consensus sleep diary47, where data are entered in a numerical format (n = 102); graphical sleep diaries (also known as raster plots), where responses are drawn on scales comprising discrete blocks of time (n = 10); morning questionnaires, single-night estimates of self-report sleep typically administered following PSG (n = 72); habitual sleep questionnaires such as the Pittsburgh Sleep Quality Index (PSQI)48, where respondents provide information on their usual sleep over a period of weeks (n = 17); morning questionnaires, where participants are queried directly by experimenters about their sleep (n = 3); graphical post-nap questionnaires that require graphical responses such as shading blocks of time (n = 1); and post-wake interviews where participants are queried about their sleep directly following natural or induced awakenings (n = 4). The specific self-report sleep questionnaire used in each study was recorded when this information was available. See supplemental materials for a qualitative overview of sleep questionnaires. We also recorded whether self-report sleep measures aimed to capture *habitual sleep*, an individual’s typical sleep over a period of weeks to a month, or sleep occurring night-by-night or sleep episode-by-sleep episode at the same time as objective measures, referred to here as *episodic* sleep. In the present review, 51 studies measured habitual sleep, 187 studies measured episodic sleep, and 7 measured both.

## 4.3 Sleep variables

A range of variables were used to measure sleep discrepancy. These are depicted below in Table 4.1.

(#tab:variables)Sleep variables used for operationalising sleep discrepancy

Variable name

Abbreviation

Calculation

Equivalent terms

Number of studies

Total sleep time

TST

Varied (Objective, Self-report)

Sleep duration

197

Sleep onset latency

SOL

Varied (Objective)

Sleep latency (SL)

142

Wake after sleep onset

WASO

Varied (Self-report)

73

Sleep efficiency

SE

Varied (Self-report, Objective)

Sleep efficiency index (SEI)

65

Time in bed

TIB

BT - RT

21

Number of awakenings

NWAK

27

Total wake time

TWT

SOL + WASO + terminal wakefulness (TWAK)

7

Sleep period time

SPT

BT - FWT

5

Sleep onset time

SOT

Time at sleep onset

Sleep onset (actigraphy)

13

Final wake time

FWT

Time at final awakening

19

Bed time

BT

Time where participant is in bed trying to sleep

Lights off (PSG)

14

Rise time

RT

Time getting out of bed

Sleep offset (actigraphy), lights on (PSG)

2

Sleep midpoint

(FWT - BT)/2

2

Sleep wake agreement (one possible objective sleep state)

6

Sleep wake agreement (two possible objective sleep states)

4

Latency to persistent sleep

LPS

Latency to 10 minutes of uninterrupted sleep

3

Sleep during subjective latency

SDSL

Minutes of objective sleep during period defined by self-report sleep latency

2

Latency-adjusted total sleep time

LA-TST

Objective total sleep time following the point of subjective sleep onset

1

Effective sleep time

EST

TST - WASO - SOL

1

Subjective wake time

SWT

WASO + SOL

1

Terminal wakefulness

TWAK

RT - FWT

Wake after sleep offset (WASF)

0\*

Intermittent wake time

IWT

No definition reported

1

Note:

Sleep wake agreement (one possible objective sleep state) 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, sleep wake agreement (two possible sleep states) 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 former approach produces a binary outcome whereas the latter produces a confusion matrix.

\* TWAK was not used to define sleep discrepancy directly by any of the included studies but is included in the table for clarity

Sleep time variables including TST, SOL, WASO, SE, and TIB preponderated in the identified studies whilst direct sleep-wake agreement was measured by only a small number. Discrepancy was investigated in variables outside of the conventional sleep time parameters depicted in the table above. Allawati et al6 compared self-report and actigraphic measures of sleep patterns including monophasic, biphasic dawn, biphasic siesta, and polyphasic. Lockley et el49, Dautovich et al50, Hanisch et al51, and Nguyen-Michel et al52 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 al53 and Chan et al54 compared self-report and actigraphic assessments of variability in TST and other sleep parameters. Thun et al55 compared self-report and actigraphic measures of morningness-eveningness. Finally, McIntyre et al56 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 sleep variables total sleep time (TST), wake after sleep onset (WASO), sleep efficiency (SE), and time in bed (TIB) varied across studies. Three types of self-report TST were observed: TST queried directly (e.g., “how many minutes did you sleep last night”; n = 115); TST calculated from other parameters such as TIB, SOL, and WASO (n = 47); and TST calculated from graphical responses (n = 7). Definitions for WASO included direct query (n = 39), calculation from numerical or graphical responses (n = 7), or the definition was not reported (n = 30). Definitions for self-report TIB included RT-LO (n = 46), FA-LO (n = 4), TST + WASO + SOL (n = 1) or definition was not reported (n = 12). SE was almost unanimously calculated as TST/TIB\*100 , although varying definitions for the TST and TIB components affect this outcome. One study57 used two definitions of SE, one comprising TST/TIB and the other TST/sleep period time (SPT).

### 4.3.2 Objective sleep variable definitions

Definitions of objective TST, SOL, and number of awakenings differed across studies. Sinclair et al58, 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 and these are depicted in Figure 4.6 below.

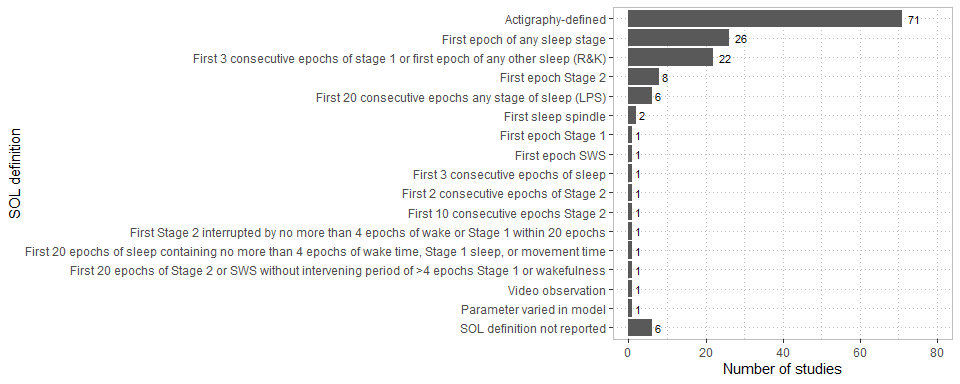


Figure 4.6: Definitions of objective sleep onset latency

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 al59, who stipulated that a period last over a minute to count as an awakening. Neu et al57 used the same definitions for objective SE as they did for 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 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.

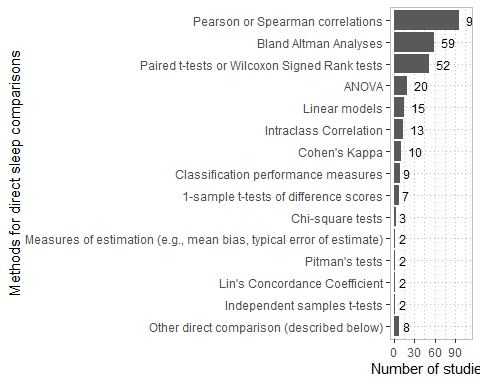
## 4.4 Method of handling repeated measurements

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. The most common methods for handling repeated measures included calculating mean values across multiple instances of recording (n = 96), pooling data across multiple instances of recording (n = 13), using repeated measures ANOVA for analyses (n = 13), calculating mean derived score values across multiple instances of recording (n = 12), using linear mixed models for analyses (n = 10), and conducting analyses separately for each instance of recording (n = 8). 75 studies included only a single instance of recording where no method of dealing with repeated measures was necessary. Less common methods included taking modal values6 or median values60,61 of multiple instances of recording, calculating the standard deviation of derived index across multiple instances of recording62, using generalised estimating equations63, and using structural equation modelling64. Mean values were a common way of handling repeated measurements for actigraphy studies (n = 85) and to a lesser extent PSG (n = 11).

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 4.7

 Note, Bland Altman analyses include Bland Altman plots and the reporting of 95% limits of agreement65. Pitman’s test (also known as the Pitman-Morgan test) is a test of differences of variances between dependent samples66,67 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 negative 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 coefficient68, partial correlation and factor analysis69, errors-in-variables regression63, repeated measures correlation70, non-parametric limits of agreement71, survival agreement72, latent correlations for testing associations at within-subjects and between-subjects level73, and structural equation modelling64.

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

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

### 4.6.1 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 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 difference 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 4.8 below.

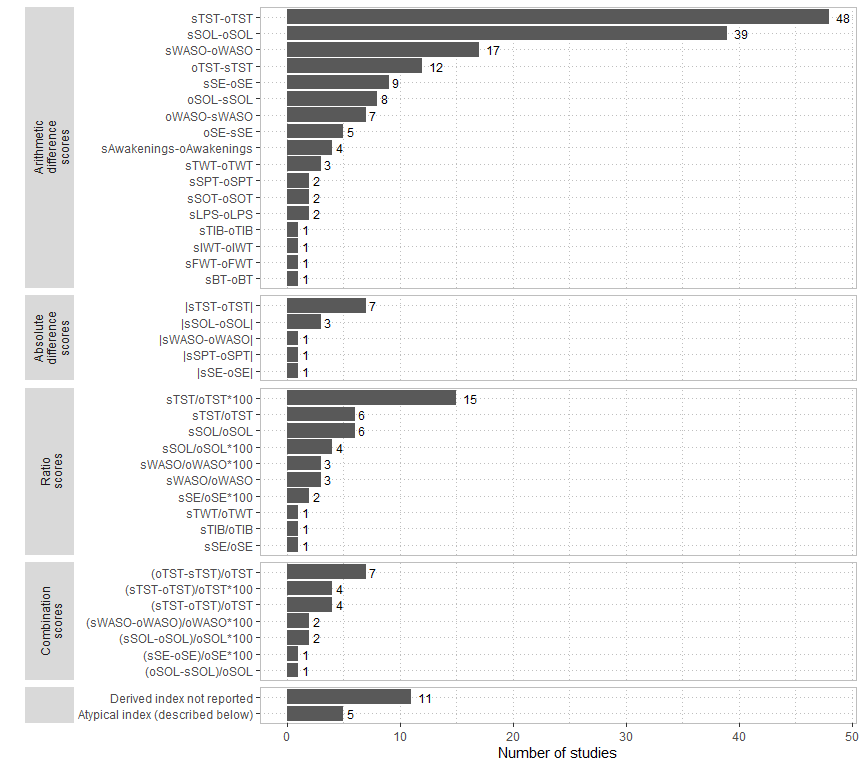


Figure 4.8: Derived indices used for operationalising sleep discrepancy

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 subtracted from self-report sleep considerably more often than vice-versa. By contrast, ratio scores did not differ in directionality, and all that were recorded featured self-report sleep as the numerator and objective sleep as the denominator. Absolute differences are unique amongst derived indices for operationalising negative sleep discrepancy as equal to positive sleep discrepancy. With the relatively few absolute difference scores noted here it appears that the literature has mostly conceived of sleep discrepancy as a directional concept. All the combination scores identified followed the general format of an arithmetic difference score divided by a component of the difference. This method of deriving scores was first devised by Manconi et al74. Their index was named the misperception index (MI) in its first iteration, is defined as oTST-sTST)/oTST, and was the most common combination score we identified. The MI was constructed to reproduce the bimodal distribution observed with OSE in insomnia patients whilst providing a strong correspondence to the difference score oTST-sTST. Possible values for the MI range from (extreme over-estimation) to +1 (extreme underestimation), although it is recommended to trim the lower limit to -174. The principle of dividing an existing difference score by the objective component has since been extended by successive authors to other sleep variables (see the “Combination scores” facet in Figure 4.8 above).

A handful of more atypical derived scores were identified. Jackowska et al75 created a sleep quality discrepancy index by subtracting a z-transformed self-report sleep quality rating from z-transformed objective SE. Kay et al62 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 al76 divided self-report sleep following experimental awakenings by objective sleep following experimental awakenings. Winer et al77 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. Seven 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. Ten studies used percentage agreement for sleep or other classification performance metrics in subsequent statistical analyses with other variables. Three studies tested the differences between correlations amongst self-report and objective sleep between groups with bootstrapped confidence intervals79, or the Fisher transformation80. Four studies 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 fragments81. 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.

## 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.

# 5 Discussion

This study systematically reviewed ways of measuring, conceptualising, and analysing sleep discrepancy. Studies varied considerably across the broad range of recorded methodological characteristics and the number of studies identified indicated a vast literature. Our findings are discussed below with recommendations for futher research where relevant.

## 5.1 Research in sleep discrepancy in marked by considerable methodological diversity

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, equipment, and algorithms and procedures to process data. Sleep time-related metrics (e.g., TST, SOL, WASO) preponderated in the identified studies, with a only small minority measuring direct sleep-wake agreement and a handful of studies measuring 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 and TIB. An exception to this general rule on the objective side was SOL, which 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 investigate 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 employed. This is unsurprising—after all, there are many ways to measure and analyse sleep—but it does have some interesting consequences for how we view sleep discrepancy.

In attempting to measure the discrepancy between two concepts it is useful to know the “discrepancy” within each concept itself. This is so that it can be certain that the discrepancy being measured cannot be accounted for by the amount of variation within each concept. It would appear 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 wakefulness82. These trends have been observed to be greater for samples experiencing chronic medical or psychiatric conditions83. Tryon84 has emphasised that these differences between polysomnography and actigraphy are systematic, rather than random, and it follows from this that the two forms of objective sleep measurement will form different kinds of sleep discrepancy.

This issue continues through finer methodological distinctions. For example, estimation of actigraphic sleep can vary substantially according to scoring algorithm and the concordance of actigraphy to PSG by algorithm can vary according to the sample in question. Actiware algorithms with the medium threshold may perform better than Cole-Kripke in healthy young adults85, the Sadeh algorithm has demonstrated higher specificity than UCSD and Cole-Kripke86–88 but may be less appropriate for assessment of sleep in those with severe obstructive sleep apnoea89. Further complicating the picture is the fact that algorithm performance will also differ according to the actigraph device used90. Distinctions continue along the process of conducting a sleep discrepancy study. The range of sleep variables available to operationalise sleep discrepancy is immense. What would it mean if WASO discrepancy was associated with a particular aspect of insomnia symptomatology but not number of awakening discrepancy? Castelnovo et al7 highlighted this issue in a review of definitions for paradoxical insomnia where little overlap was found between individuals that misperceive TST and misperceive SOL.

The distinctions continue even within sleep variables themselves. We identified two principal ways of calculating self-report TST from diaries and sleep questionnaires: querying participants directly about how much sleep they had (e.g., “how many hours did you sleep last night?”) and calculating TST from other parameters that were queried directly (e.g., TST = TIB - SOL - WASO - TWAK). The latter method is recommended by Buysse et al91 and is the usual practice when using the Consensus Sleep Diary47, a questionnaire that does not contain a direct query for TST in its standard version. Alameddine et al92 compared direct and indirect (i.e., calculated) self-report measures of TST and found that indirect estimates tended to exceed direct estimates. In this study, sleep discrepancy was overall negative across the 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 (i.e., reduced sleep discrepancy). For each of these examples, differences in sleep discrepancy are observed across varied methodological approaches in ways that are likely to be systematic. This is a significant issue for studies investigating the relationship between sleep discrepancy and another construct as the variance accounted for by the span of possible approaches may well exceed that of the effect the researchers are looking for.

This issue extends beyond the status of sleep discrepancy as a concept and affects the pragmatics of research in the area. 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 significance93. As evidenced by the methodological diversity highlighted in 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 in Table 4.1 may be chosen as an alternative analytic decisions during analysis. When the different possible definitions of each of these variables are also enumerated, the number of possible decisions seems endless. Note, this issue is not confined to the case of a researcher deliberately exploring analytical alternatives following a null result. In a problem referred to as the garden of forking paths94, 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.

Addressing these issues may take a number of approaches. A stronger research focus on methods, investigating the impact of changes in methodology would be helpful overall. 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. Theoretical justification or similar 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 reduce methodological variance in this particular area, although the large range of available devices (see 11.5) and proprietary nature of some algorithms e.g., Boyne et al31 may prove an impediment to this. For the time-being, in light of the large amount of unreported features of actigraphy found in this review, it would be helpful to follow the recommendations of Ancoli et al95 to report device manufacturer, device model, name and version of software, parameters of data collection including epoch length and sampling rate, and algorithms used. Finally, for any study investigating the relationship of sleep discrepancy with other constructs, pre-registration of hypotheses and plans for data collection and analysis96 is likely to be helpful in minimising inflated Type I error through post-hoc methodological decisions.

## 5.2 Definitions of objective sleep onset latency are multifarious and mostly abritrary

Definitions of objective SOL vary considerably in the sleep discrepancy literature. Among PSG studies, the two most common approaches were dependent on standard definitions provided by scoring guidelines: Rechstaffen & Kales (R&K)97 and the American Academy of Sleep Medicine (AASM)98. In R&K, sleep onset is defined by three consecutive epochs of stage 1 sleep or one epoch of stage 2 sleep97. For AASM, by contrast, an epoch of any stage of sleep indicates sleep onset98. Subjective 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 sleep99. 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)60 and complex definitions from Means et al3 and Lehrer et al100 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 night101.

Saline et al102 noted a potential problem 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).

Sleep onset is a continuous process for which it is difficult to identify a clear start-point84. For example, with PSG scored by AASM criteria, 50% of a 30-second epoch is needed to exhibit sleep for the scoring of a first sleep stage. This means sleep latency is defined as the number of epochs preceding the first uninterrupted ~16 seconds of an EEG depicting activity consistent with sleep. An individual could conceivably achieve this 16-second threshold within two minutes, wake up, and not return for another two hours (SOL = 2 minutes). Equally, an individual could spend a two hour period getting 14-second blocks of sleep before achieving a consolidated bout of sleep (SOL = 120 minutes). These are extreme examples, but they highlight the difficulty with defining a single point of sleep onset. Of course, a line needs to be drawn somewhere, but the position of this line appears to be an arbitrary decision.

In view of these issues, three options are recommended in the context of sleep discrepancy research. The first is to 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 underestimation101,102 it makes sense to use a longer criterion than a shorter one. LPS also has the advantage of being simpler than some alternatives (see 4.6). The second option is to 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. The third option is to avoid SOL as a sleep variable and to model sleep perception parameters during the sleep onset period according to Hermans et al101. The latter two options have the added advantage of operationalising sleep discrepancy without the use of derived scores—the problems with which are discussed in the following paragraph.

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

To map the boundaries of the concept of sleep discrepancy, we included any studies comparing objective sleep with an equivalent measure of self-report sleep. From the very few studies identified investigating sleep patterns or other sleep-related behaviours it appears that sleep discrepancy is mostly restricted to discordance in sleep states (e.g., wakefulness versus sleep) or discordance in sleep time parameters (e.g., total sleep time). It may be helpful to consider sleep discrepancy, as so defined, in relationship to sleep misperception. These two terms have been used interchangeable in the past and the problems with doing this have been noted by a number of authors84,103. 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 sleep104, and other dissociations between the EEG and sleep-related physiological processes, have been observed under some conditions105. Moreover, conventional sleep scoring is but one way of classifying EEG data and more subtler systems exist, including the cyclic alternative pattern106.

Whilst it may not be possible to directly measure sleep misperception for these reasons, sleep discrepancy can be closer or further to sleep misperception conceptually depending on its operational definition. Closest are studies measuring sleep-wake agreement or classification using EEG under laboratory conditions. In a case where a participant who, being asleep for five minutes, is woken by a technician and reports complete wakefulness for the preceding period, only the fallibility of objective recording can account for a conceptual distinction between sleep discrepancy and true sleep-state misperception. This fundamental sleep discrepancy represented by direct sleep-wake agreement can be contrasted with sleep discrepancy represented by sleep time variables (e.g., TST, SOL). Moving from sleep-wake agreement to sleep time variables introduces additional factors that may account for the incongruence between self-report and objective sleep and hence provides a broader definition of sleep discrepancy. On the objective side, PSG potentially introduces artefact from transient (e.g., <15 second) awakenings107 and the arbitrary nature of SOL definitions (see section 5.2). Actigraphy introduces the potential for immobile wake to be scored as sleep86,108 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 biases109 as potential factors contributing to sleep discrepancy. See Harvey et al110 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 yet sleep discrepancy further. A more global sleep discrepancy may be represented by comparisons of habitual self-report sleep with aggregated 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 effect111,112) are additionally introduced.

## 5.4 Derived variables are extremely 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 problems113–115 that are severe enough to warrant discontinuing their use in sleep discrepancy research. A detailed treatment of these problems is beyond the scope of this discussion. Stated briefly, in a relationship with another variable, the effect of each component of a derived (e.g., the difference between self-report and objective sleep) is confounded such that it is not possible to determine whether self-report sleep, objective sleep, or some combination of the two are driving the relationship114. Moreover, derived scores impose inappropriate constraints on relationships between other variables that are often not entailed by, or else completely contradictory to, stated hypotheses114. 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 (see 4.6.2).

## 5.5 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 nightly or episodic 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 and some individuals will overestimate sleep116. 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 nightly level. In other cases, linear mixed models, generalised estimating equations, and structural equation models were methods identified in this review that do not inherit the same problems with averaging across repeated measures.

## 5.6 Correlations have sometimes been used inappopriately 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 measures117. 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.

## 5.7 Sleep quality discrepancy is conceptually unclear

Sleep quality discrepancy was measured by a small number of studies in this review, according to varying strategies. Sleep quality discrepancy is a difficult topic for two reasons. First, there is no consensus approach to operationalising sleep quality. A recent review of methods for measuring sleep quality identified an immense range in strategies, especially for objective measures118. 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 & Edinger119). 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.

## 5.8 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 misreported109 highlights the significance of this issue. We noted that a single study in the present review addressed this problem directly. Krahn et al120 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.

## 5.9 The scope of sleep discrepancy research is likely to have been underestimated

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. A prior review of paradoxical insomnia and subjective-objective sleep discrepancy8 identified a total of 40 records. Although conducted four years prior, this review used broader inclusion criteria extending to paradoxical insomnia, the parameters for which do not typically involve direct comparisons of self-report and objective sleep. A corollary to this underestimation of breadth is 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 emphasised121 and a mechanistic role for sleep misperception has been suggested for disorders outside of insomnia122.

## 5.10 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.

## 5.11 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 understanding 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 progressive 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…

# 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 Funding

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# 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.

# 11 Appendices

## 11.1 Search strategies

Search strategies for databases searched using the Ovid system are available in Table 11.1. Search strategies for other databases are listed in Table 11.2.

(#tab:ovid)Search strategy for Ovid databases

Step

Terms and operators

Records

Embase

1

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

488

2

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

193243

3

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

1676

4

(sleep\* and (“over estimat*” or ”over report*” or “under estimat*” or ”under report*” or overestimat\* or overreport\* or underestimat\* or underreport\* or discrepan\* or concordan\* or agreement or disagreement or discordan\* or congruen\* or incongruen\*)).mp.

9362

5

2 or 3

193302

6

4 and 5

1234

7

1 or 6

1569

PsycINFO

1

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

175

2

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

57592

3

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

59

4

(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.

2112

5

2 or 3

57592

6

4 and 5

346

7

1 or 6

471

Medline

1

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

260

2

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

139088

3

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

561

4

(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.

5280

5

2 or 3

139088

6

4 and 5

692

7

1 or 6

875

(#tab:databases)Search strategy for other databases

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\*))

761

CINAHL Plus

(“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\*))

310

Scopus

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

826

Web of Science

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

1288

Proquest Theses and Dissertations Global

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\*))))

90

## 11.2 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 comparisons only, single-case design)

1. Reference lists were not searched for additional citations as planned in the protocol

## 11.3 PRISMA-ScR checklist

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

Section

Item

PRISMA-ScR Checklist Item

Location reported

Title

Title

1

Identify the report as a scoping review.

1

Abstract

Structured summary

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

2

Objectives

4

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

Methods

Protocol and registrations

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.

3.1

Eligibility criteria

6

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

3.2

Information sources

7

Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.

3.4

Search

8

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

3.1

Selection of sources of evidence

9

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

3.5

Data charting process

10

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

3.6

Data items

11

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

3.7

Critical appraisal of individual sources of evidence

12

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).

Formal quality assessment was not conducted

Synthesis of results

13

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

3.8

Results

Selection of 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.

4

Characteristics of sources of evidence

15

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

4.1

Critical appraisal within sources of evidence

16

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

Formal quality assessment was not conducted

Results of individual sources of evidence

17

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

4.2

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

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

5

Limitations

20

Discuss the limitations of the scoping review process.

5.10

Conclusions

21

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

5.11

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

## 11.4 Additional tables

Full descriptions of study characteristics are available in Table 11.4.

(#tab:studychar)Characteristics of included studies

Study

Country of origin

Sample characteristics

Sample size

Ahn et al123

Korea

Patients >55 years with insomnia disorders

33

Al Lawati et al6

Oman

Healthy Omani nationals

321

Alameddine et al92

USA

Participants referred to a sleep centre for PSG

879

Ansok et al124

USA

Patients with rotator cuff tears

18

Argyropoulos et al125

United Kingdom

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

40

Aritake-Okada et al126

Japan

Healthy males

22

Arora et al127

United Kingdom

Adolescents aged 11-13

255

Auger et al128

USA

Patients referred to an academic sleep centre

84

Baek et al53

Korea

Shiftwork nurses

94

Baillet et al5

France

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

45

Baker et al129

South Africa

Healthy young subjects

20

Barbosa et al130

Brazil

Visually impaired individuals and participants without visual impairment

77

Bastien et al131

Canada

Individuals with chronic psychophysiological insomnia, paradoxical insomnia and good sleepers

88

Bean et al132

New Zealand

Chronic pain patients

47

Bensen-Boakes et al133

Australia

Participants with comborbid insomnia and OSA

145

Bian et al134

China

Inpatients with schizophrenia

148

Bianchi et al135

USA

Patients referred to a sleep centre

312

Bianchi et al60

USA

Healthy subjects undergoing in-lab sleep experiment

44

Billings136

USA

Firefighters

24

Bonnet & Moore99

USA

Young adults

12

Broomfield & Espie137

United Kingdom

Individuals complaining of sleep-onset insomnia

34

Brychta et al138

Iceland

15-year, then 17-year old students of the same cohort

144

Caia et al139

Australia

Professional rugby league athletes

63

Campanini et al140

Brazil

School teachers

163

Carter et al141

USA

Collegiate athletes

121

Castelnovo et al142

Switzerland

Patients with insomnia

249

Castillo et al143

USA

Patients referred to a sleep centre for PSG

405

Cederberg et al144

USA

Patients with multiple sclerosis

49

Chan et al145

USA

Community dwelling older adults with insomnia

62

Chan et al54

USA

Individuals with fibromyalgia and Insomnia

223

Chen et al146

Taiwan

Individuals with osteoarthritis

30

Chervin & Guilleminault147

USA

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

147

Cho et al148

Korea

Participants from the sleep heart health study

2540

Choi et al149

Korea

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

420

Chou et al150

USA

Cognitively normal and mildly impaired older adults

293

Chung et al151

Korea

Outpatients with schizophrenia

66

Combertaldi & Rasch152

Switzerland

Young healthy students

24

Conroy et al153

USA

Individuals experiencing insomnia in recovery from alcohol dependence

21

Creti et al154

Canada

Participants with chronic fatigue syndrome

49

Crönlein et al155

Germany

Patients receiving CBT-I for insomnia

92

Currie et al156

Canada

Individuals experiencing insomnia in recovery from alcohol dependence

56

Curtis et al157

USA

Participants with fibromyalgia and insomnia

199

D’Aoust et al158

USA

Informal caregivers of persons with dementia

53

Dautovich et al50

USA

Older adults who nap habitually

100

De Francesco et al80

United Kingdom

People with HIV and people without HIV matched on demographic variables

461

De Jaeger et al159

Belgium

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

19

Dean et al160

USA

Adults with inoperable non-small cell lung cancer

26

Devine et al161

USA

Army Reserve Officers’ Training Corp Cadets

286

Dietch & Taylor162

USA

Representative community-based normative sample

80

Dinapoli et al163

Italy

Older adults with mild cognitive impairment and subsyndromal depression

59

Dittoni et al164

Italy

Chronic primary insomnia patients

66

Dorrian et al165

Australia

Commercial passenger airline pilots

306

Dorsey & Bootzin166

USA

Undergraduate students

31

Downey & Bonnet167

USA

Subjective insomniacs

10

Duarte et al168

Brazil

Patients undergoing PSG for suspected sleep-disordered breathing

727

Duarte et al169

Brazil

Individuals with sleep disorders and contrls

2004

Dunican et al170

Australia

Judo athletes

23

Dzierzewski et al171

USA

Older adults with insomnia

159

Edinger & Fins2

USA

Outpatients with insomnia presenting to a sleep disorders centre

173

Espie et al26

United Kingdom

Individuals with insomnia

20

Etain et al172

France

Adults with bipolar disorder and healthy controls

154

Facco et al173

USA

Nulliparous women enrolled in the first trimester of pregnancy

752

Feige et al174

Germany

Insomnia patients and good sleeper controls

100

Feige et al175

Germany

Individuals with paradoxical insomnia and good sleeper controls

200

Feng & Svetnik73

United Kingdom

Primary insomnia patients

n/a

Fernandez-Mendoza et al176

USA

Insomniacs and controls

866

Finan et al177

USA

Participants with opioid use disorder

55

Franklin & Svanborg178

Sweden

Individuals referred to sleep center for suspected OSA

100

Friedmann et al64

Germany

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

184

Gaina et al179

Japan

Healthy junior high school children

42

Ghadami et al180

Iran

War veterans diagnosed with chronic PTSD

32

Gibson et al70

Australia

Australian army recruits

59

Girschik et al68

Australia

Women recruited from the community

56

Gonzalez et al181

USA

Individuals with bipolar type I

39

Gooneratne et al182

USA

Older adults with and without insomnia complaint

200

Goudman et al183

Belgium

Patients with failed back surgery syndrome treated with spinal chord stimulation

39

Goulart et al184

Brazil

Healthy males with normal sleep randomised to three experimental groups

31

Guedes et al72

Brazil

Adolescents

37

Gökce et al185

Germany

Young adults in Munich

74

Hall et al186

USA

Women with PTSD secondary to interpersonal violence

45

Hanisch et al51

USA

Prostate cancer patients undergoing androgen therapy

60

He et al187

China

Adults participants subject to COVID-19 lockdown provisions in China

70

Heath et al188

Australia

Adolescents

385

Herbert et al189

United Kingdom

Individuals with insomnia symptoms

42

Hermans et al190

Netherlands

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

46

Hermans et al81

Netherlands

Insomnia patients and healthy controls

231

Hermans et al191

Netherlands

Older adults with and without insomnia

41

Hermans et al101

Netherlands

Participants with insomnia on a waitlist for CBT-I

31

Herring et al192

USA

Urban low-income pregnant women

80

Hita-Yañez et al193

Spain

Patients with MCI and healthy elderly

50

Hodges et al194

USA

Cocaine-dependent persons admitted to an inpatient research facility

43

Hoogerhoud et al195

Netherlands

Patients receiving index or maintenance ECT for a depressive episode

12

Hsiao et al196

Taiwan

Healthy young adults

36

Huang et al197

China

Primary insomnia patients and healthy controls

170

Hughes et al198

USA

Vulnerable older adults participating in a Veterans Administration Adult Day Health Care (ADHC) program

59

Hur et al199

Canada

Patients with interstitial lung disease

111

Ihler et al200

France, Norway

Individuals with bipolar disorder and healthy controls

196

Jackowska et al75

United Kingdom

Women working at University College London and neighbouring institutions

179

Jackson et al78

USA

Adults enrolled in a large longitudinal study

1910

Jackson et al79

USA

African-American adults

821

Janků et al201

Czech Republic

Insomnia patients

36

Jungquist et al202

USA

Community-dwelling adults

300

Kang et al203

USA

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

82

Kaplan et al204

USA

Individuals with bipolar disorder and age and sex-matched controls

54

Kaufmann et al205

USA

Individuals with bopolar disorder and healthy controls

85

Kawada206

Japan

Healthy university students

76

Kay et al207

USA

Individuals with paradoxical insomnia and good sleeper controls

62

Kay et al208

USA

Older adults with and without insomnia

114

Kay et al62

USA

Older adults with and without sleep complaint

103

Keklund & Akerstedt209

Sweden

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

37

Kennedy et al210

Ireland

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

54

Khou et al211

USA

Community dwelling older adults with and without mild Alzheimers disease

86

King et al212

USA

Female undergraduates enrolled in an interior design programme

28

Kishikawa et al213

Japan

Outpatients with primary insomnia undergoing CBT-I

52

Kobayashi et al214

USA

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

103

Kolling et al215

Germany

German undergraduate and graduate physical education students

72

Kong et al216

China

Children recruited from primary and secondary schools in Hong King

133

Krahn et al120

USA

Psychiatric inpatients

30

Kreutz et al217

Germany

Breast cancer patients starting neoadjuvant chemotherapy

54

Krishnamurthy et al218

USA

Bipolar disorder patients and healthy controls similar in age, race, and sex

54

Kryger et al219

Canada

Patients with chronic insomnia

16

Krystal & Edinger220

USA

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

30

Krystal et al221

USA

Individuals with subjective insomnia, objective insomnia and normal controls

50

Kundu et al222

India

Individuals with chronic insomnia and obstructive sleep apnoea

32

Kung et al223

Taiwan

Taiwanese adults with major depression

30

Lan Chun Yang et al224

Canada

Participants diagnosed with mTBI/concussion

37

Laranjeira et al225

Brazil

Individuals referred to a sleep centre

248

Lastella et al226

Australia

Well-trained male soccer players

12

Lauderdale et al63

USA

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

647

Lecci et al (study 2)227

Switzerland

Insomnia patients and healthy subjects

34

Lecci et al227

Switzerland

Population-based sample

2092

Lee et al228

Korea

Patients with OSA

707

Lee et al229

Korea

Adults with insomnia

105

Lee230

United Kingdom

Adults aged 20 or above

8438

Lehrer et al100

USA

Middle-aged community-dwelling women

323

Lewis59

United Kingdom

Healthy young men

8

Lipinska & Thomas231

South Africa

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

60

Liu et al232

China

Patients diagnosed with OSA

355

Liu et al233

China

Healthy young adults

10

Locihova et al234

Czech Republic

Patients admitted to an intensive care unit of a hospital

20

Lockley et al49

United Kingdom

Blind individuals

49

Lubas et al61

USA

Participants enrolled in a longitudinal study of survivors of childhood cancer

477

Lund et al235

USA

Older adults with comorbid insomnia

60

Ma et al236

USA

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

638

Maes et al237

Belgium

Female patients diagnosed with primary insomnia and healthy female controls

28

Maich et al238

Canada

Individuals with insomnia and good sleeper controls

74

Majer et al239

USA

Individuals with chronic fatigue and non-fatigued controls

75

Manconi et al (study 2)74

Italy

159 patients with primary insomnia

159

Manconi et al74

Italy, USA

Normal subjects

288

Maric et al240

Switzerland

Healthy right-hand males

14

Martinez et al241

Brazil

Patients referred to a university-affiliated sleep clinic for PSG

5764

Matousek et al242

Czech Republic

Patients with minor depression, complaining of insomnia

28

Mazza et al243

France

Children aged 8-9 years recruited from elementary schools

76

McCall & McCall244

USA

Patients diagnosed with current major depressive episode and chronic insomnia

54

McCall et al245

USA

Individuals undergoing PSG for suspected sleep apnoea

84

McIntyre et al56

New Zealand

Healthy women late in third trimester

30

Means et al3

USA

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

101

Mendelson et al76

USA

Individuals with insomnia and age and sex matched controls

20

Mendelson246

USA

Participants who complained of poor sleep

8

Mercer et al247

USA

Individuals with insomnia and good sleepers

22

Meyer et al248

United Kingdom

Outpatients with schizophrenia

14

Miner et al249

USA

Community-dwelling older adults

5835

Moore et al250

USA

43 women with insomnia who had completed treatment for breast cancer

43

Most et al251

Netherlands

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

81

Mundt et al252

USA

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

113

Nam et al253

Korea

Patients referred to a sleep clinic for evaluation of snoring/OSA

50

Narisawa et al254

Japan

Participants with subjective sleep difficulty

50

Nazem et al255

USA

Male veterans with traumatic brain injury

19

Neu et al57

Belgium

Individuals with chronic fatigue and female controls

40

Nguyen-Michel et al52

France

Older adults referred for insomnia complaints or suspected sleep apnoea

135

Normand et al256

Canada

Paradoxical insomnia, psychophysiological insomnia, good sleepers

70

O’Brien et al257

USA

Treatment-seeking overwieght/obese participants

63

Okifuji & Hare258

USA

Patients with fibromyalgia

75

Okun et al259

USA

Pregnant women

104

Orta et al260

Chile

Female primary caregivers of children with disabilities

175

Ouellet & Morin261

Canada

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

28

Park et al262

USA

Postmenopausal women

384

Perlis et al263

USA

Female fibromyalgia patients

20

Perlis et al264

USA

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

27

Pinto Jr et al265

Brazil

Individuals selected from a university sleep laboratory

199

Provencher et al266

Canada

Individuals with psychophysiological insomnia, paradoxical insomnia, and good sleepers

67

Reess et al267

Germany

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

159

Regestein et al69

USA

Healthy, postmenopausal women having hot flash activity

88

Richardson et al268

Australia

Adolescents diagnosted with delayed sleep-wake phase disorder

103

Ritter et al269

Germany

Euthymic outpatients with bipolar disorder and healthy volunteers

50

Rogers et al27

USA

Patients with narcolepsy and matched controls

50

Saline et al102

USA

Adult patients referred to a clinical sleep laboratory

643

Santos et al270

Brazil

Participants in a longitudinal study

2036

Sato et al271

Japan

Patients experiencing psychophysiological insomnia

20

Scarlett et al272

Ireland

Community-dwelling older adults

1520

Schneider-Helmert & Kumar273

Switzerland

Participants with primary insomnia

128

Schokman et al274

Sri Lanka

Sri Lankan adults

175

Schulz & Walther275

Germany

Individuals referred to a sleep centre for investigation of sleep disorders

117

Segura-Jimenez et al276

Spain

Women with fibromyalgia and healthy controls

198

Sharkey et al277

USA

Patients in a methadone maintenance therapy for opioid dependence

62

Sharman et al278

United Kingdom

Healthy sleepers

16

Short et al279

Australia

Adolescents

385

Signal et al280

USA

Flight crew

21

Silva et al281

USA

Participants over 40

2113

Sinclair et al58

Australia

Patients with traumatic brain injury and non-injured controls

42

Slightam et al282

USA

Veterans with PTSD and demographically similar controls

120

Smagula et al283

USA

Males

2850

So et al284

USA

Prepubertal children

55

Somma et al285

Italy

Participants with insomnia and community dwelling adults matched on demographic variables

60

Spielmanns et al286

Germany

CPAP users

26

Spinweber et al287

USA

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

60

Sprajcer et al288

Australia

Healthy adult male on-call workers

72

St-Onge et al289

USA

Multi-racial, multi-ethnic sample of adults

113

Stout et al290

USA

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

37

Sun-Suslow et al291

USA

People with and without HIV

94

Takano et al292

Belgium

Adults

54

Tang & Harvey (study 2)293

United Kingdom

Healthy good sleepers

93

Tang & Harvey293

United Kingdom

Healthy good sleepers

54

Tang & Harvey294

Various

Individuals with primary insomnia

48

Tang et al (study 2)295

United Kingdom

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

38

Tang et al295

United Kingdom

Poor and good sleepers

60

Thun et al55

Norway

University students

166

Thurman et al71

USA

Healthy participants

30

Tomita et al296

Japan

patients complaining of excessive daytime sleepiness

28

Topalidis et al297

Various

Healthy participants

21

Trajanovic et al4

Serbia, USA

Patients referred to a sleep clinic

136

Tremaine et al298

Australia

Children aged 11-16

65

Tremaine et al299

Australia

Children and adolescents

66

Trimmel et al300

Austria

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

303

Trimmel et al300

Austria

Patients referred to sleep clinic in a department of neurology

303

Tsuchiyama et al301

Japan

Patients with major depression admitted to a psychiatric hospital

23

Usui et al302

Japan

Older and younger adults

39

Valko et al303

Switzerland

Patients referred to a sleep clinic for PSG

3303

Vallieres & Morin304

Canada

Participants with chronic primary insomnia

17

Van Den Berg et al305

Netherlands

Community-dwelling older adults

969

Vanable et al28

USA

Patients referred to sleep clinic with various sleep disorders

104

Wang et al306

Taiwan

Heart failure patients

43

Wang et al307

Canada

Naval sailors

66

Werner et al308

USA

Women with PTSD experiencing PTSD-related sleep disturbance

51

Williams et al309

USA

Community-dwelling older adults

142

Wilson et al310

Canada

Individuals experiencing insomnia associated with chronic musculoskeletal pain

40

Wilson et al311

Australia

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

64

Winer et al77

USA

Cognitively normal older adults

89

Wolfson et al312

USA

High school students

302

Xu et al313

China

Young adults

47

Yamakita et al314

Japan

School-aged children

58

Yeung et al315

China

Individuals with insomnia undergoing placebo acupuncture

86

Yoon et al316

Korea

Patients with insomnia

150

Zak et al317

USA

Healthy premenopausal women

71

Zhu et al318

USA

Adults with type II diabetes

53

Zinkhan et al319

Germany

Participants recruited from the community

100

Zou et al320

China

Insomnia disorder patients and well-matched healthy controls

64

te Lindert et al116

Netherlands

Individuals with insomnia disorder and individuals without sleep complaints

236

Full qualitative methodological details for actigraphy studies are available in Table 11.5.

(#tab:bigacti)Qualitative actigraphy characteristics

Study

Actigraph device

Software

Algorithm

Algorithm reference

Rest interval definition

1

Chou et al150

Actiwatch 2

Actiware

Actiware Low (20)

31

Not reported

3

Janků et al201

MotionWatch 8

MotionWare

MotionWare

CamNTech, UK

Event marker –> sleep diary

4

King et al212

Actiwatch Spectrum Plus

not reported

Actiware Medium (40)

31

Not reported

5

Lehrer et al100

Actiwatch AW64

Actiware

Actiware Medium (40)

31

Informed by sleep diaries, decided by study staff

7

Segura-Jimenez et al276

SenseWear Pro3 Armband

SenseWear Professional

SenseWear

32

Set intervals

8

Slightam et al282

Actiwatch AW64

Actiware

Actiware Medium (40)

31

Event markers –> activity, sleep diary

10

Williams et al309

Actiwatch-L

Actiware-Sleep

Actiware (not reported)

31

Not reported

11

Al Lawati et al6

SOMNOwatch plus

Domino Light

Domino Light

33

Manual scoring

12

Ansok et al124

Actiwatch Spectrum Plus

not reported

Cole-Kripke

34

Event markers –> sleep diary

14

Auger et al128

Actiwatch AW64

Actiware

Kripke

35

Automated –> sleep diary

15

Baillet et al5

MotionWatch 8

MotionWare

MotionWare

CamNTech, UK

Event markers –> sleep diary

18

Billings136

ActiGraph wGT3X-BT

ActiLife

Cole-Kripke

34

Sleep diary, inconsistenies reviewed with participant

19

Brychta et al138

ActiGraph GT3X+

ActiLife

Sadeh

36

Visual inspection, sleep diaries

20

Cederberg et al144

ActiGraph GT3X+

ActiLife

Cole-Kripke

34

Sleep diary

21

Chan et al54

Actiwatch 2

not reported

not reported

Complex criteria involving sleep diary, activity levels, light

25

Currie et al156

Mini Motionlogger

not reported

Cole-Kripke

34

Event marker

26

Dietch & Taylor162

Actiwatch Spectrum

Actiware

Actiware Low (10)

31

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

28

Dunican et al170

not reported

Readiband Sync

not reported

Not reported

29

Facco et al173

not reported

not reported

Actiware Medium (40)

31

Not reported

32

Ghadami et al180

not reported

not reported

not reported

Not reported

33

Girschik et al68

Actiwatch Spectrum

Actiware

Actiware Medium (40)

31

Event marker –> sleep diary

36

Herring et al192

Actiwatch AW64

Actiware

Actiware (not reported)

31

Event markers –> sleep diary

37

Hoogerhoud et al195

not reported

not reported

Actiware (not reported)

31

Not reported

38

Ihler et al200

Actiwatch AW7

Actiwatch activity & sleep analysis

Actiware (not reported)

31

Event markers

39

Jackowska et al75

Actiheart monitor

Actiheart

Actiheart

37

Sleep logs; heart rate; activity

41

Kaplan et al204

Actiwatch AW64

Actiware

Actiware (Low, Medium, High)

31

Set to lights off and lights-on from PSG

42

Kawada206

Actiwatch

not reported

Actiware Medium (40)

31

Not reported

43

Kay et al208

Actiwatch 2

Actiware

Actiware Medium (40), Cole-Kripke

31;34

Event marker; sleep diary; activity; light

44

Kay et al62

Actiwatch-L

not reported

Actiware High (80)

31

Not reported

47

Khou et al211

ActiGraph GT3X+

ActiLife

Cole-Kripke

34

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

48

Kong et al216

not reported

not reported

not reported

Not reported

49

Krahn et al120

not reported

not reported

Cole-Kripke

34

Scored manually (tech was blinded to sleep diary)

52

Liu et al233

Fitbit Alta

Fitbit software

Fitbit

88

Automatic (heart rate + activity)

53

Lockley et al49

Motionlogger, Mini Motionlogger

Action 3

not reported

Sleep diaries

58

Mazza et al243

Actiwatch 2

Actiware

Actiware Medium (40)

31

Event marker, activity, light

61

Moore et al250

Actiwatch 2

Actiware

Actiware Medium (40)

31

Not reported

62

Most et al251

Actiwatch

Actiware

Actiware (not reported)

31

Vinyl-covered pressure sensitive pad and light-dependent resistor

63

Mundt et al252

Actiwatch 2

Actiware

Actiware High (80)

31

Sleep diaries

65

Nazem et al255

Actiwatch 2

Actiware

Actiware (not reported)

31

Not reported

67

Okifuji & Hare258

Micro Mini Motionlogger

Action

not reported

Not reported

68

Orta et al260

ActiSleep

ActiLife

Cole-Kripke

34

Not reported

71

Regestein et al69

not reported

not reported

Actiware Medium (40)

31

Sleep diary

72

Ritter et al269

SOMNOWatch Plus

Domino Light

Cole-Kripke

34

Event markers

74

Sato et al271

not reported

not reported

Cole-Kripke

34

Not reported

76

Sharman et al278

Actiwatch AW4

Actiwatch Activity and Sleep Analysis

Actiware Medium (40)

31

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

78

Spielmanns et al286

PAM Polar A300

not reported

not reported

N/a

82

Wang et al307

Micro Motionlogger

Action 4

not reported

Event markers

83

Werner et al308

not reported

Action W

UCSD

38

Automatic

87

Barbosa et al130

ActiGraph GT3X+

ActiLife

Cole-Kripke

34

Sleep diary, activity, light

90

Broomfield & Espie137

Actiwatch 2

not reported

not reported

Event markers

91

Caia et al139

Actiwatch 2, ActiGraph GT3X+, Readiband

not reported

not reported

Not reported

92

Campanini et al140

Actiwatch 2

Actiware

Actiware Medium (40)

31

Algorithms supplemented by event marker

93

Carter et al141

Actiwatch Spectrum Pro

not reported

Actiware Medium (40)

31

Light

97

Chung et al151

Actiwatch 2

Actiware

Actiware Medium (40)

31

Event marker or sleep diary

98

Dautovich et al50

Actiwatch-L

Actiware-Sleep

Actiware High (80)

31

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

99

De Jaeger et al159

Actiwatch Spectrum Plus

Actiware

Actiware (not reported)

31

Not reported

100

Dean et al160

Octagonal Sleep Watch

Action 3

not reported

Sleep diary

104

Gonzalez et al181

Motionlogger

Action

UCSD

38

Not reported

105

Goudman et al183

Actiwatch Spectrum Plus

Actiware

Actiware (not reported)

31

Not reported

107

Hanisch et al51

Actiwatch AW64

Actiware-Sleep

Actiware (not reported)

31

Sleep diary

111

Hughes et al198

Actiwatch Spectrum

not reported

Actiware Medium (40)

31

Not reported

112

Kaufmann et al205

Actisleep-BT

not reported

not reported

Not reported

113

Kreutz et al217

ActiGraph wGT3X-BT

ActiLife

Cole-Kripke, Tudor-Locke

34;45

Tudor-Locke algorithm

114

Krishnamurthy et al218

not reported

ActiLife

ActiLife

39

Not reported

118

Lauderdale et al63

Actiwatch AW16

not reported

not reported

Event markers –> sleep log

119

Lubas et al61

Motionlogger

not reported

not reported

Event markers

120

Maich et al238

Actiwatch Score

Mini-Mitter Actiwatch Software

Actiware Low (20)

31

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Okun et al259

Actiwatch

Actiware

Actiware Medium (40)

31

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Park et al262

Actillume I

Actillume Algorithm

Actillume

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Sleep diary, notes, light, Webster’s rules

131

Scarlett et al272

GENEactiv

GENEactive

Micro-Electro-Mechanical Systems

40

N/a

132

Schokman et al274

Actiwatch Spectrum Pro

Actiware

Actiware Medium (40)

31

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

133

Stout et al290

Micro Sleep Watch

not reported

not reported

Not reported

134

Tang & Harvey293

Mini Motionlogger Basic

not reported

Cole-Kripke, Webster’s rescoring rules

34

Defined in-lab

135

Thun et al55

Actiwatch AW7

Actiwatch Activity and Sleep Analysis

Actiware Medium (40)

31

Not reported

136

Tomita et al296

MicroMini RC

Action W2

not reported

Manually corrected, using diaries where necessary

137

Tremaine et al299

not reported

Actiware-Sleep

Actiware Medium (40)

31

Not reported

139

Usui et al302

Motionlogger

not reported

Cole-Kripke

34

N/a

142

Wilson et al310

Mini Motionlogger

not reported

Cole-Kripke, Webster’s rescoring rules

34

Not reported

143

Wolfson et al312

Mini Motionlogger

Action W2

Sadeh

36

Sleep diary

144

Yamakita et al314

Lifecorder

Sleep Sign Act

Sleep Sign Act

Kissei Comtec Co, Japan

Set manually

145

Yeung et al315

Actiwatch 2

Actiware, Action W

Actiware (not reported)

31

Not reported

148

Baek et al53

Actiwatch Spectrum Pro

Actiware

Actiware Medium (40)

31

Sleep diary

149

Chan et al145

Actiwatch-L

Actiware-Sleep

Actiware Medium (40)

31

Sleep diary

150

Chen et al146

not reported

not reported

not reported

Not reported

154

Heath et al188

Micro Mini Motionlogger

Action W2

Sadeh

36

Not reported

156

Kobayashi et al214

Mini Motionlogger

Action W2

Sadeh

36

Sleep diary, habitual sleep questionnaire

157

McCall & McCall244

Actiwatch AW64

Actiware

Actiware Medium (40)

31

Not reported

159

Vallieres & Morin304

IM Systems Actigraph

Individual Monitoring Systems

IM Systems

Individual Monitoring Systems, Inc., USA

Not reported

160

Zhu et al318

ActiGraph wGT3X

ActiLife

Actiware Medium (40), Cole-Kripke

31;34

Not reported

161

Hall et al186

Motionlogger Basic

Action W

UCSD

38

N/a

163

Kolling et al215

SenseWear MF Armband

SenseWear Professional

SenseWear

32

Event marker –> activity

164

Locihova et al234

ActiGraph wGT3X-BT

ActiLife

Cole-Kripke

34

Externally defined

167

Winer et al77

Micro Motionlogger

Action W2

Sadeh

36

Sleep diary and event markers

168

D’Aoust et al158

Actiwatch-L

Actiware

Actiware (not reported)

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Not reported

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Dorrian et al165

not reported

Actiware-Sleep

Actiware Medium (40)

31

Not reported

173

O’Brien et al257

Motionlogger Basic

Action W

Sadeh

36

Sleep diary, discrepancies queried

174

St-Onge et al289

ActiGraph GT3X+

not reported

not reported

Not reported

176

Arora et al127

ActiGraph GT3X+

not reported

not reported

Sleep diary

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Curtis et al157

Actiwatch 2

Actiware

Actiware (not reported)

31

Sleep diary

181

Devine et al161

Actiwatch 2

Actiware

Actiware Medium (40)

31

Automatically defined, sleep diary/ other daily schedule info

183

Dzierzewski et al171

Actiwatch Spectrum

not reported

Actiware (not reported)

31

Not reported

184

Etain et al172

Actiwatch AW7

Actiwatch Activity and Sleep Analysis

Actiware (not reported)

31

Sleep diary and event markers

186

Gibson et al70

ActiGraph GT9X Link

ActiLife

Cole-Kripke

34

Externally defined (platoon sleep record)

187

Gökce et al185

ActiGraph wGT3X-BT

Actiware

Cole-Kripke

34

Software-defined

188

Herbert et al189

MotionWatch 8

MotionWare

Sadeh

36

Sleep diary

191

Jackson et al78

Actiwatch Spectrum

Actiware-Sleep

Actiware (not reported)

31

Event marker, sleep diary, light sensor

193

Kung et al223

Mini Motionlogger

Action W2

not reported

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

196

Lee230

ActiGraph GT3X+

not reported

Machine learning algorithm

41

Not reported

199

Meyer et al248

Fitbit Charge HR

Sleepsight

Fitbit

88

N/a

200

Kishikawa et al213

Actiwatch 2

Actiware

Actiware Medium (40), Cole-Kripke

31;34

Event markers

201

Santos et al270

Actiwatch 2

not reported

not reported

Event marker

203

Smagula et al283

SleepWatch-O

Action W2

Cole-Kripke, UCSD

34;38

Sleep diary –> manual scoring

204

te Lindert et al116

GENEactiv

GENEactive

Actiware (Low, Medium, High)

31

Sleep diary

205

Thurman et al71

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Fatigue Science Software

Fatigue Science

42

Sleep offset/onset defined by sleep state (9pm-11am)

206

Topalidis et al297

Xiaomi Mi Band 3, GT3X ActiGraph

ActiLife

Cole-Kripke

34

N/a

207

Van Den Berg et al305

Actiwatch AW4

Actiware

Actiware Low (20)

31

Event marker –> sleep diary

208

Zak et al317

Mini Motionlogger, Actigraph Model AAM-32

Action

Cole-Kripke

34

Event marker

209

De Francesco et al80

ActiGraph wGT3X-BT

not reported

not reported

Not reported

210

Gaina et al179

Actiwatch

not reported

not reported

Sleep diary

211

Guedes et al72

Mini Motionlogger Basic

Action W2

Sadeh

36

Sleep/activity log

213

Sinclair et al58

not reported

Actiware

Actiware Medium (40)

31

Sleep diary

214

Takano et al292

ActiGraph wGT3X-BT

Actiware

Cole-Kripke

34

Unsure/ not reported

215

Tang et al295

Mini Motionlogger Basic

Action W

Cole-Kripke

34

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

216

Tang & Harvey294

Mini Motionlogger Basic

Action W

Cole-Kripke

34

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

217

Wang et al306

Motionlogger

Action W2

not reported

Not reported

219

Creti et al154

Actitrac

IM Systems Software

IM Systems

Individual Monitoring Systems, Inc., USA

Externally set (PSG)

222

He et al187

ActiGraph wGT3X-BT

ActiLife

Cole-Kripke, Choi, Troiano

34;44;46

N/a or not reported

223

Hur et al199

ActiGraph wGT3X-BT

ActiLife

Cole-Kripke

34

Sleep diaries

224

Jungquist et al202

Camntech Pro-Diary

MotionWare

MotionWare

CamNTech, UK

Not reported

230

Short et al279

Motionlogger

Action W2

Sadeh

36

Sleep diary

231

So et al284

Micro Motionlogger

not reported

Sadeh

36

Event marker

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Sun-Suslow et al291

ActiGraph GT9X Link

not reported

Cole-Kripke

34

Sleep diary –> manual

234

Tremaine et al298

not reported

Actiware-Sleep

Actiware Medium (40)

31

Sleep diary

235

Jackson et al79

ActiGraph GT3X+

ActiLife

Cole-Kripke

34

Manual: sleep diary, activity, light

237

Bean et al132

Actiwatch AW64

Cambridge Neurotechnology Sleep Analysis 5.5

Actiware (not reported)

31

Sleep diary

238

Miner et al249

SleepWatch-O

Action W2

UCSD

38

Software and sleep diaries

239

Richardson et al268

Micro Mini Motionlogger

not reported

Sadeh

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Manual and sleep diary

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Friedmann et al64

Move II

not reported

Barouni

43

Sleep onset during fixed interval: 20:00-00:00

243

Signal et al280

Actiwatch

Actiware-Sleep

Actiware (Low, Medium, High)

31

Event marker, sleep diary

244

Narisawa et al254

Actiwatch

not reported

not reported

Activity levels

245

Tang & Harvey (study 2)293

Mini Motionlogger Basic

not reported

Cole-Kripke

34

Defined in-lab

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Tang et al (study 2)295

Mini Motionlogger Basic

Action W

Cole-Kripke

34

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.

(#tab:sleepwake)Direct sleep-wake agreement studies

Study

Sample characteristics

Sleep variables

Sleep-wake agreement type

PSG setting

60

Mendelson et al76

individuals with insomnia and age and sex matched controls

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

Binary

in-lab

73

Rogers et al27

patients with narcolepsy and matched controls

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

Confusion matrix

home-based

101

Dorsey & Bootzin166

undergraduate students

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

Confusion matrix

in-lab

123

Mendelson246

participants who complained of poor sleep

Participant report of having been awake/asleep following experimental awakenings

Binary

in-lab

124

Mercer et al247

individuals with insomnia and good sleepers

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

Binary

in-lab, home-based

139

Usui et al302

older and younger adults

sleep/ wake agreement, 10-minute epochs

Confusion matrix

n/a

152

Downey & Bonnet167

subjective insomniacs

SOL, participant sleep/wake judgement following experimental awakenings

Binary

in-lab

165

Nguyen-Michel et al52

older adults referred for insomnia complaints or suspected sleep apnoea

Perception of sleep during nap (binary)

Binary

in-lab

170

Dorrian et al165

commercial passenger airline pilots

TST; sleep/wake

Confusion matrix

n/a

229

Schulz & Walther275

individuals referred to a sleep centre for investigation of sleep disorders

sleep / wake judgement following induced awakenings

Binary

in-lab

Note:

Binary sleep-wake involved measuring at one or multiple instances whether a participant’s reported sleep state matched the objective sleep state upon which the query was conditional (e.g., participants were only queried 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 are called so as the former approach produces a binary outcome whereas the latter produces a confusion matrix.

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