Relationship, differences, and agreement between objective and subjective sleep measures in chronic spinal pain patients with comorbid insomnia : a cross-sectional study

ABSTRACT

Sleep disturbances are one of the most frequent reported problems in people with nonspecific chronic spinal pain (nCSP) and presents an additional treatment challenge. Interventions targeting sleep problems are mainly based on subjective sleep complaints and don't take objective sleep into consideration. The aim of this cross-sectional study was to evaluate the relationship and conformity between self-reported and objectively measured sleep parameters (i.e. questionnaire vs. polysomnography and actigraphy). The baseline data of 123 people with nCSP and comorbid insomnia who are participating in a randomized controlled trial was analyzed. Pearson correlations were used to investigate the relationship between objective and subjective sleep parameters. Differences between objective and subjective sleep parameters were analyzed using t-tests. Bland-Altman analyses were performed to quantify and visualize agreement between the different measurement methods. Except for the significant, moderate correlation between perceived time in bed (TIB) and actigraphic TIB ($r=.667$, $p<.001$), all other associations between subjective and objective measures were rather weak ($r<.400$). Participants underestimated their total sleep time (TST) (Mean Difference [MD]=-52.37 [-67.94, -36.81], $p<.001$) and overestimated sleep onset latency (SOL) (MD=13.76 [8.33, 19.20], $p<.001$) in general. The results of this study suggest a discrepancy (differences and lack of agreement) between subjective and objective sleep parameters in people with nCSP and comorbid insomnia. No or weak associations were found between self-reported sleep and objectively measured sleep. Findings suggest that people with nCSP and comorbid insomnia tend to underestimate TST and overestimate SOL. Future studies are necessary to confirm our results.

Keywords: Chronic spinal pain, chronic neck pain, chronic back pain, sleep assessment, polysomnography, actigraphy, self-report

Relationship, differences and agreement between objective and subjective sleep measures in chronic spinal pain patients with comorbid insomnia: a cross-sectional study

Thomas Bilterys[1-3]*, PT, MSc, Eveline Van Looveren[1-3], PT, MSc, Anneleen Malfliet[1,3,4,5], PT, PhD, Jo Nijs[1,3,4,6], PT, PhD, Mira Meeus[2,3,7], PT, PhD, Lieven Danneels[2], PT, PhD, Kelly Ickmans[1,3,4,8], PT, PhD, Barbara Cagnie[2], PT, PhD, Dorien Goubert[2], PT, PhD, Maarten Moens[3,9,10,11], MD, PhD, Liesbet De Baets[1,3], PT, PhD, Wouter Munneke[1,3], PT, MSc, Olivier Mairesse[12,13], PhD.

[1] Pain in Motion Research Group (PAIN), Department of Physiotherapy, Human Physiology and Anatomy, Faculty of Physical Education and Physiotherapy, Vrije Universiteit Brussel, Brussels, Belgium

[2] Department of Rehabilitation Sciences, Faculty of Medicine & Health Sciences, Ghent University, Ghent, Belgium

[3] Pain in Motion International Research Group, www.paininmotion.be

[4] Department of Physical Medicine and Physiotherapy, University Hospital Brussels, Brussels, Belgium

[5] Research Foundation Flanders (FWO), Brussels, Belgium.

[6] Department of Health and Rehabilitation, Unit of Physiotherapy, Institute of Neuroscience and Physiology, University of Gothenburg, Sweden.

[7] Department of Rehabilitation Sciences and Physiotherapy (MOVANT), Faculty of Medicine and Health Sciences, University of Antwerp, Antwerp, Belgium.

[8] Movement & Nutrition for Health & Performance research group (MOVE), Department of Movement and Sport Sciences, Faculty of Physical Education and Physiotherapy, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium

[9] Department of Neurosurgery and Radiology, University Hospital Brussels, Brussels, Belgium

[10] Center for Neuroscience, Vrije Universiteit Brussel, Brussels, Belgium

[11] Stimulus research group, Vrije Universiteit Brussel, Brussels, Belgium

[12] Brain, Body and Cognition, Faculty of Psychology and Educational Sciences, Vrije Universiteit Brussel, Brussels, Belgium

[13] Sleep Laboratory and Unit for Clinical Chronobiology, Brugmann University Hospital, Brussels, Belgium

*Corresponding author: Thomas Bilterys, Pain in Motion Research Group (PAIN), Department of Physiotherapy, Human Physiology and Anatomy, Faculty of Physical Education and Physiotherapy, Vrije Universiteit Brussel, Brussels, Belgium

Email: thomas.bilterys@vub.be

Number of text pages: 30

Number of Figures: 4

Number of tables: 5

Introduction

Nonspecific chronic spinal pain (nCSP), defined as chronic neck and/or back pain not attributable to a specific pathology, is a prevalent chronic pain conditions with a significant impact on health care cost, disability and quality of life. [22; 26; 31; 43; 44] Within the nCSP population, sleep disturbances are frequently reported with more than 50% having comorbid insomnia.[3; 7; 20; 48; 61] Furthermore, insomnia is associated with depressive symptoms, anxiety and pain catastrophizing, can negatively influence physical and psychological functioning and can increase disability, pain severity, and economic burden.[11; 29; 33; 47; 56; 59] Available evidence demonstrates a bidirectional relationship between pain and sleep problems, in which sleep disturbances are a stronger predictor for pain.[12; 67] Considering the available evidence and the impact of insomnia, addressing sleep problems as an integral part of the nCSP management seems warranted.

The management of insomnia is often mainly based on self-reported sleep. This could be expected since the diagnosis of insomnia disorder relies on self-reported symptoms (i.e., there is no insomnia when there is no complaint).[4] However, the majority of insomniacs tend to misperceive their sleep time and it appears that objective and subjective sleep measures assess different sleep constructs.[21; 49; 57] Both actigraphy and polysomnography assessments provide unique information in objective manner which can help to reveal and address underlying sleep problems. However, since actigraphic sleep estimated are based on movement, motionless wake is likely to register as sleep. To fine-tune the algorithmic actigraphy reports, the use of a sleep diary is recommended.[5; 23] Currently it is unclear whether stand-alone actigraphy (i.e., without sleep logs) could be used to reliably detect sleep. Although commercial wearables often use other parameters (i.e., light, heart rate and skin conduction) to more reliably detect different sleep stages, manufacturers commonly use their own algorithmic scoring which they generally withheld.[58] Research-grade activity trackers mostly depend on motion only.

Currently, there is still an important knowledge gap regarding the treatment of objective-subjective sleep discrepancy.[1; 10; 16; 49] Depending on the sleep perceptions, different therapeutic components of cognitive behavioral therapy for insomnia (CBT-I) might play important roles.[34]

Furthermore, the presence of nCSP and the mutual interactions with sleep introduce an additional challenge to identify the most efficient treatment approach.[12; 67]

Given 1) that most studies in people with nCSP only make use of self-reported sleep measures,[35; 67] do not focus on the relation and difference between objective and subjective sleep measures,[3; 7; 61] or have a small sample and are most-likely underpowered,[46; 65] 2) the varying nature of sleep problems in nCSP and the importance of identifying objective-subjective sleep discrepancy,[10; 49] and 3) the lack of information regarding the clinical usefulness of stand-alone actigraphy to assess sleep in people with nCSP, the aim of this study was to add to a better understanding of sleep problems in people with nCSP and expand on existing literature by comparing subjective and objective sleep parameters, investigating their relationship and examining the agreement between objective and subjective assessment methods in people with nCSP.

Methods

Study design

This is a cross-sectional study, using the baseline data of 123 participants from an ongoing multi-center randomized controlled trial (RCT) (registered at Clinicaltrials.gov [NCT03482856], expected finalization in June 2022). The full study protocol of the ongoing trial is published elsewhere.[39] This cross-sectional study aims to investigate and compare objective and subjective sleep assessments in people with nCSP. The ongoing trial was approved by the local ethics committees of the University Hospital Ghent and University Hospital Brussels (reference no. BUN 670201835625). Signed informed consent was obtained from all participants prior to any study procedure. Socio-demographics and additional information (including the nature, severity and impact of insomnia [insomnia severity index]; sleep propensity [Epworth sleepiness scale]; mental and physical fatigue [Brugmann fatigue scale]; level of anxiety and depression [hospital anxiety and depression scale]; Perceived health or health-related quality of life [Short Form Health Survey-36]; pain intensity and impact of pain on functioning [Brief Pain Inventory]; and self-reported signs of central sensitization [Central

sensitization inventory]) were collected from every participant.

Setting, participants, and sample size

Participants were recruited from the participating universities and university hospitals (Ghent and Brussels), occupational health services, primary care practices, through adverts and flyers, and social media. Potential participants received written information about the study and were requested to fill out an online questionnaire which was used to screen for in- and exclusion criteria. Eligible people were verbally informed and telephone screened prior to study participation. The telephone screening was used to confirm the eligibility and ask additional questions if the answers on the online questionnaire did not suffice.

Inclusion criteria were: (1) being a native Dutch speaker, (2) aged between 18 and 65 years, (3) having nCSP for at least 3 days/week, for at least 3 months, including chronic low back pain (CLBP), failed back surgery syndrome [i.e. surgery more than 3 years ago and anatomically successful surgery without symptom disappearance], chronic traumatic and non-traumatic neck pain), (4) having insomnia (i.e., self-reported sleep difficulties described as > 30 minutes of wake time during the night [including sleep latency, wake after sleep onset, early morning awakenings or a combination] for > 3 days/week for > 6 months, and which causes distress or impairment in daytime functioning despite having adequate opportunity and circumstances to sleep.), and (5) refraining from analgesics, caffeine, alcohol or nicotine 48 hours prior to the assessments. Since this study used the baseline data of an RCT investigating an intervention, (6) participants had to be available and willing to participate in therapy sessions and were not allowed to continue any other therapies (i.e. other physical therapy treatments, acupuncture, osteopathy, etc.), except for usual medication and did not receive any form of pain neuroscience education or sleep training before. Additionally, participants were asked not to initiate new pharmacological treatments 6 weeks prior to and during participation and not to undertake exercise (< 3 metabolic equivalents) 3 days before the assessments. Exclusion criteria were: (1) suffering from any specific medical condition possibly related to their pain (e.g. neuropathic pain, a history of neck/back surgery in the past 3 years, osteoporotic vertebral fractures, rheumatologic

diseases); (2) having any severe underlying comorbid sleep pathology (e.g. apnea, restless leg syndrome, etc.) identified through baseline data of polysomnography or diagnosed before participation); (3) being pregnant or pregnancy (including having given birth) in the preceding year; (4) history of specific spinal surgery; (5) suffering from thoracic pain in absence of neck or low back pain (LBP); (6) being a shift worker, (6) being diagnosed with depression, (7) being diagnosed with a chronic widespread pain syndrome(e.g. fibromyalgia, chronic fatigue syndrome); and (8) having a body mass index >30. As the data was originally collected as part of an RCT evaluating an intervention, (9) people living more than 50 km away from the treatment location were excluded to avoid dropout because of practical considerations.

Sample size calculation

The sample size was estimated specifically for this cross-sectional study which aims to evaluate the relationship and conformity between self-reported and objectively measured sleep parameters. Sample size calculation was performed with G*Power 3 (Düsseldorf, Germany) based on a pilot study of O'Donoghue.[46] The required number of participants was calculated for a correlation analysis based on a medium effect size (|ρ|) of 0.298. A total of 113 participants was required to detect a medium effect size allowing for a type I error of .05 and aiming for 95% power.

Procedure

After the initial screening process and enrolment, all participants completed the baseline assessment including online questionnaires, actigraphy (1 week) and home-based polysomnography (1 night). Online questionnaires were used to assess socio-demographic (gender, age, body mass index, level of education, pain duration), subjective sleep quality (using the Pittsburgh sleep quality index [PSQI]), and all other secondary self-reported outcome measures (including Insomnia severity index, the Epworth sleepiness scale, the Brugmann fatigue scale, the Hospital anxiety and depression scale, Short Form Health Survey-36, the Brief Pain Inventory and the Central sensitization inventory). Home-

based polysomnography (Alice PDX system, Philips Respironics Inc™) was used to assess sleep objectively. Additionally, sleep-wake was also monitored during one week using actigraphy (GT9X Link, Actigraph). All participants were also screened for severe, primary sleep pathologies using the data from the same home-based polysomnography assessment.[9; 45]

Outcome Measures

Subjective sleep assessment - Self-Report

Self-reported sleep was evaluated using the PSQI which is commonly used to assess subjective sleep quality. This short questionnaire consists of 19 items, offering seven component scores and one global score ranging from 0 to 21.[15] A higher score indicates a worse self-reported sleep quality. The PSQI has a high test-retest reliability and good validity.[6; 42] The following questions of the PSQI were used to extract the subjective sleep parameters SOL, TST, TIB and SE: "During the past month, when have you usually gone to bed at night?", "During the past month, how long has it usually take you to fall asleep each night?", "During the past month, when have you usually gotten up in the morning?" and "During the past month, how many hours of actual sleep did you get at night?".

Objective Sleep Assessment – Home-based Polysomnography

All participants underwent a one night evaluation using the portable monitor (Alice PDX) in the comfort of their own home to counteract first night effects encountered by insomniacs.[28] A standard polysomnography montage was used and included electroencephalogram, electrooculogram, chin electromyogram (EMG), leg EMG, electrocardiogram, breathing effort parameters, airflow parameters, oxygen saturation, and body position, according to American Academy of Sleep Medicine recommendations.[9] A trained researcher set-up the polysomnography measurements, advised the patient with written and verbal instructions and gave a brief demonstration after the set-up. Participants were asked to activate the event marker to indicate "lights out" and "lights on". The data

were anonymized and manually scored by a trained researcher. Sleep stages, arousals, and abnormal respiratory events were quantified according to AASM 2017 criteria (version 2.4).[9] The polysomnography assessment provides the following parameters: time in bed (TIB), total sleep time (TST), sleep onset latency (SOL), wake duration after sleep onset (WASO), early morning awakening (EMA), sleep staging, sleep efficiency (SE). Polysomnography is considered as the "gold standard" for monitoring sleep.[40; 50] To reduce first night effects, reversed first night effects and state-specific effects based on environment (e.g., sleep lab),[28] all participants were monitored in the comfort of their own home and bed by ambulatory polysomnography. Given the similar assessment qualities of ambulatory polysomnography and the convenience of testing at home, home-based polysomnography was the preferred choice so participants could sleep more naturally and in familiar surroundings during the assessment[13; 45]

Objective Sleep Assessment – Actigraphy

Three-axis accelerometer activity monitors (GT9X-BT, Actigraph Corporation, LLC, USA) were used to assess the sleep patterns for one week. Participants received the instruction to wear the activity monitors continuously (day and night) at their non-dominant wrist. ActiLife6 (Actigraph, Corporation, LLC, USA) was used to analyze the data captured with the activity monitors. The following sleep variables were extracted from the activity monitors: TST, WASO, TIB and SE. Actigraph devices are commonly used in research and are validated for general measures of sleep.[1; 8; 52] The Cole-Kripke sleep scoring algorithm was used to determine all sleep variables.[17] The average values of all sleep variables measured during one week by the actigraphy were used in the statistical analyses.

Statistical Analysis

SPSS 26.0 (IBM, Armonk, NY, USA) was used to perform the statistical analyses. Descriptive statistics were computed for all demographic characteristics, and primary and secondary outcomes. Histograms, Q-Q plots and Kolmogorov-Smirnov tests were used to check the normality of the

distribution of the differences in the dependent variables (sleep parameters). Difference of 2.2 times the interquartile range were considered as outliers.[30] Pearson's product moment correlation coefficients were calculated between subjective sleep parameters and polysomnography parameters to assess the association between subjective and objective sleep measures. Dependent t-tests were used to compare mean values for objective and subjective TIB, TST, WASO, SOL and SE. Bland-Altman analyses were performed to quantify and visualize agreement between self-report measures and polysomnography by studying the mean difference and constructing limits of agreement. The Bland-Altman plots are scatter plots with the Y-axis representing differences between the two measures of specific sleep parameter and the X-axis representing the mean of these two measures. Additionally, the differences were also plotted as percentages. The agreement between the methods was evaluated by looking at the average of the differences (which should be zero when the variability is only linked to analytical imprecision), differences at different magnitudes to investigate possible relationship between measurement error and the true value (represented by an estimate based on the mean of the two measurements) and the limits of agreement (Mean ± 1.96 * Standard deviation (SD)).[25] Although polysomnography is considered as the gold standard to evaluate sleep,[40; 50] it is known that there is some variation in manual sleep scoring. A recent review found an inter-rater reliability for manual, overall sleep scoring of 0.76 Cohen's kappa.[37] Since polysomnography is considered the gold standard to asses sleep, the difference in manual scoring between two assessors can be considered as the limit for acceptable agreement between two different measure methods. Therefore, we added agreement limits, representing a 24% difference, to the percentage-based plots. The pairwise deletion method was used to handle missing values.

Additionally, the statistical analyses were repeated to assess the association, the comparison of mean values and the agreement between the actigraphy parameters and subjective parameters, and actigraphy parameters and polysomnography parameters.

Results

After the initial screening of selection criteria, a total of 146 people with nCSP and comorbid insomnia were enrolled in the study. Based on the results of the polysomnography analysis, 20 participants were excluded because of a primary sleep pathology (i.e., apnea (n=17) and periodic leg movements in sleep (n=3)). There were 3 additional late exclusions based on the selection criteria: 1 participant was excluded because of widespread pain and 2 more participants were excluded because of recent spinal surgery. A flowchart with details about the missing data is presented in Figure 1**.** Polysomnography data of one participant (who refused to participate in the polysomnography measurement) was missing. There was no actigraphy data available of 7 participants because of several reasons: 1 actigraph monitor was defect, the actigraph data of 2 participants got corrupted and in 4 cases the data could not be downloaded from the actigraph monitors. Based on the a priori set criterion of a difference of 2.2 times the interquartile range, 3 outliers were identified. Despite being outliers, all three values were considered realistic when checking the dataset and the original records. Therefore, all outliers were considered as a part of the dataset and included in all analyses.

The participants had a mean age of 40.20 years (±11.18) and 68% of the participants (84/123) were female. More details regarding the descriptive data of the participants are presented in TABLE 1.

Associations between subjective (self-report) and objective sleep parameters (polysomnography).

A significant association was found between self-reported and polysomnographic TIB (r=.365, p=<.001). The associations between self-reported and polysomnographic SOL, TST and SE were non-significant and very weak (r=.113, p=.216; r=.112, p=.219; r=.175, p=.054, respectively). All correlations with corresponding p values are presented in TABLE 2.

Associations between actigraphy parameters and sleep parameters measured by other methods.

Significant associations were found between self-reported and actigraphic TST (r=.243, p=.009), self-reported and actigraphic TIB (r=.667, p=<.001), actigraphic and polysomnographic WASO (r=.296,

p=.001), actigraphic and polysomnographic TST (r=.296, p=.001), actigraphic and polysomnographic TIB (r=.281, p=.002) and actigraphic and polysomnographic SE (r=.299, p=.001). No association was found between self-reported and actigraphic SE (r= -.004, p=.965). All correlations with corresponding p values are presented in TABLE 3.

Difference and agreement between self-reported sleep parameters and sleep parameters measured by polysomnography

A significant difference was found between self-reported and polysomnographic SOL, TST and SE (p=<.001). The self-reported SOL was longer compared to the polysomnographic SOL (Mean difference: -13.76 [-19.20, -8.33,]). The self-reported TST was shorter, and the self-reported SE was lower compared to the values based on the polysomnography (Mean difference: 52.37 [36.81, 67.94]; Mean difference: 13.05 [10.76, 15.35], respectively). A small but non-significant difference was found between self-reported and polysomnographic TIB with a higher TIB measured by the polysomnography (Mean difference: -13.08 [-26.56, .39], p=.057). All details are presented in TABLE 4. Since the same data is used in the t-test, the Bland-Altman plots (Figure 2) present the same mean differences. Wide limits of agreement were found for differences in SOL (-73.22 to 45.68), TST (-117.83 to 222.58), TIB (-160.44 to 134.27) and SE (-12.06 to 38.16). An overestimation of SOL was found based on the higher mean difference in self-reported SOL compared to SOL measured by polysomnography. There is no significant mean difference in TIB. The TST is on average underestimated by the participants (mean difference below zero-line). Consequently, this also leads to a general underestimation of SE. The limits of agreements based on the large variations in differences exceed the proposed acceptable agreement limits (24%-difference limits) in all sleep parameters. Bland-Altman plots for the data regarding the sleep variables measured by self-report and polysomnography are presented in Figure 2.

Difference and agreement between self-reported sleep parameters and sleep parameters measured by actigraphy

There was a significant difference between self-reported and actigraphic TST, TIB and SE. The self-reported TST was shorter compared to the actigraphic TST (Mean difference: 34.44 [20.83, 48.06], p=<.001). Self-reported TIB was higher compared to the TIB measured with actigraphy (Mean difference: -9.95 [-18.23, -1.67], p=.019). Consequently, self-reported SE was lower compared to the actigraphic SE (Mean difference: 8.54 [6.04, 11.03], p=<.001). No actigraphic SOL was identified. All details are presented in TABLE 5. Regarding the level of agreement between self-report and actigraphy measurement, the Bland-Altman plots (Figure 3) of TST and SE show wide limits of agreement (-110.66 to 179.54; -18.08 to 35.16). Smaller limits of agreement were found for TIB (-98.15 to 78.25). Compared to actigraphy, participants underestimated TST and SE, and overestimated TIB (which is visualized in the Bland-Altman plots by the position of the mean difference line in relation to the zero line). Large variations in differences between self-reported and actigraphy measured SE and TST where found, which results in relative wide limits of agreements, exceeding the 24%-difference limits. An acceptable agreement (within 24%-difference limits) was found between TIB measured by self-report and TIB measured by actigraphy. Bland-Altman plots for the data regarding the sleep variables measured by self-report and actigraphy are presented in Figure 3.

Difference and agreement between sleep parameters measured by actigraphy and polysomnography

Actigraphic WASO, TST and SE was significantly different from polysomnographic WASO, TST and SE. The amount of actigraphic WASO was almost two times the amount of polysomnographic WASO (Mean difference: -35.28 [-41.76, -28.80], p=<.001). The actigraphic TST and SE was lower compared to polysomnographic TST and SE (Mean difference: 18.82 [6.79, 30.85], p=.002; Mean difference: 4.41 [3.08, 5.75], p=<.001, respectively). There was no significant difference in the amount of TIB (Mean difference: -1.46 [-15.02, 12.10], p=.831). No actigraphic SOL was identified. All details are presented in TABLE 5. Very wide limits of agreements were found for differences in WASO measured by actigraphy and WASO measured by polysomnography (-104.38 to 33.82). Limits of agreement regarding TST (-109.41 to 147.05), TIB (-145.94 to 143.02) and SE (-9.81 to 18.64) were relatively smaller compared to the limits of agreement regarding WASO but were still wide. In general, the actigraphy measurement overestimates WASO and underestimates TST compared to the

polysomnography measurement. Based on the relative wide limits of agreement (and thus large variations in differences), no agreement in measurement of WASO, TST and TIB was found. An acceptable agreement (within the 24%-difference limits) was found for the measurement of SE by actigraphy and polysomnography. Bland-Altman plots for the data regarding the sleep variables measured by actigraphy and polysomnography are presented in Figure 4.

Discussion

Our results indicate that perceived sleep can differ from objective findings (polysomnography) in patients with nCSP and comorbid insomnia. On average, participants underestimate TST (±30 minutes to 1 hour) and overestimate TIB (±13 minutes) and SOL (±14 minutes). No clear agreement was identified between subjective and polysomnographic measures.

A moderate correlation between self-reported and actigraphic TIB was found. Only an acceptable agreement was identified for the measurement of TIB between self-report and actigraphy, and SE between actigraphy and polysomnography. The significant difference between the mean SE measured by actigraphy and polysomnography combined with the smaller limits of agreements suggests that there might be a systematic difference.

The wide limits of agreement suggest that there is poor agreement between objective (polysomnography and actigraphy) and subjective sleep measurements. While the results of the t-tests indicate whether there is a general over- or underestimation, the Bland-Altman plots provide more insight and show large variations between participants. People with a relative lower SE appear to underestimate their SE more compared to those with a higher SE (Figure 2 and 3). Overestimation of TST and TIB by actigraphy compared to polysomnography seems to be more common when TST and TIB are lower, while underestimation appears more common when TST and TIB are higher (Figure 4).

Our results are in line with the findings of 2 previous pilot trials using actigraphy during 3 (n=15) and 7 consecutive nights (n=16) which found significantly higher levels of subjective than objective sleep disturbance in CLBP patients.[46; 65] Another study with 77 LBP patients used a sleep diary and

armband (SenseWear-Pro 3) to assess sleep for 7 days.[2] Contrary to our results, they found higher subjective SE (±11%) and TST (±75 minutes) compared to the objective sleep parameters in people with nonspecific LBP.[2] Since the presence of sleep complaints was not an eligibility criterion in their study and sleep misperception is relatively prominent in insomniacs, it is likely that sleep discrepancy is more common in our study.[63]

When investigating the relation between self-reported and polysomnographic parameters, only a moderate association between perceived and polysomnographic TIB was found. TIB is the only sleep parameter that is not significantly different between the self-report and the polysomnographic measurement which suggests that subjective and objective findings represent different sleep dimensions/aspects. The associations between polysomnographic and actigraphic sleep parameters are rather weak, highlighting that actigraphy measures sleep differently compared to polysomnography.[66]

Strengths and limitations

This study has several strengths including the sufficient sample size, the use of both actigraphy and polysomnography, and the use of Bland-Altman plots. Moreover, the study tried to account for many variables through questioning of sleep environment, substance use, shiftwork, pregnancy, depression, and body mass index.

Nevertheless, this study has several limitations that need to be discussed. First, no sleep diary but the PSQI was used to assess subjective sleep, which examines the perceived average sleep quality over the previous month. Yet, which the general consensus is that a sleep diary should be used to asses subjective sleep parameters,[32] the usage of a sleep dairy might influence the perceived sleep as people tend to focus more on their sleep. One questionnaire is probably less impactful and still gives a good indication of subjective sleep parameters. However, the use of a sleep diary would have been more precise and could have improved the accuracy of the actigraphy results. Additionally, the use of the questionnaire could introduce recall bias and might be influenced by most recent experiences.

Second, the different measurement methods encompass a different timeframe. The polysomnography data was based on a one-night home-based measurement which might be influenced by the measurement moment and the situational context. However, previous studies indicated that sleep parameters measured by polysomnography/electroencephalogram seem to have trait-like characteristics and stay relatively stable over time, even under extreme conditions.[14; 38; 51; 64] Therefore, sleep parameters based on the polysomnography are likely to be representative for the average sleep variables in similar environments and conditions. Nevertheless, state-specific effects and within-person variation (e.g., weekdays versus weekends) that we could not control for might still be present (which limits the comparability with the other measurements over multiple days).[19; 36] While the timeframe of both self-report (previous month) and actigraphy measurement (one week) was different, they both represent average values and are likely to vary less than a comparison with a one night measurement. Even though the self-report data examines the perceived average over one month, it is assessed retrospective by one single questionnaire which might introduce recall bias or be influenced by recent experiences. Overall, the different timeframes of the 3 methods might influence the sleep estimates which warrants caution with the interpretation of the results. Third, stand-alone actigraphy was used to assess sleep. The scoring algorithm for the actigraphy data was unable to identify any SOL which suggests that it was unable to differentiate between motionless wake and sleep (i.e., SOL is scored as sleep), SOL could not be differentiated from time out of bed (i.e. "lights out" could not be identified) or a combination. It is highly likely that the lack of estimated actigraphic SOL led to a higher SE, higher TST and/or lower TIB estimates. Consequently, differences in self-reported and actigraphic estimates are likely partially explained by the inability to identify SOL. Therefore, our results suggest that a sleep diary should be used in combination with actigraphy to be able to at least accurately identify "light off" and "lights on" in people with nCSP and comorbid insomnia. Last, these findings might not be generalizable to other chronic pain populations.

Relevance, implications and future directions

Considering the limitations, one should be cautious to interpret the results as the differences might be partly explained by the limitations. Nevertheless, the limitations highlight the importance of several aspects which should be considered for future research to be able to confirm our results and make firm conclusions. First, subjective and objective measurements with a similar timeframe should be used. The use of multiple nights polysomnography assessment would give more insight in sleep/wake patterns in people with nCSP and comorbid insomnia and results in better comparability as the same nights would have been measured. Second, a sleep diary should be used to measure subjective sleep as this would reflect the daily perceived sleep outcomes better compared to a single questionnaire. Additionally, a sleep diary should be used to increase the accuracy of actigraphy measurement. Despite the limitations, our results still show relatively large inter-individual differences between objective and subjective sleep outcomes. Nevertheless, our findings are rather suggestive and confirmation of future studies is necessary.

In cases with high level of sleep discrepancy and limited objective sleep deficit, it might be beneficial to specifically target the misperceptions regarding sleep discrepancy in the initial phase of the treatment. Several small studies suggest that interventions which teach people how to interpret the result of a polysomnography/actigraphy measurement, explain the objective sleep data and explore the discrepancy have the potential to correct sleep misperceptions.[24; 60] Harvey et al. (2012) evaluated several possible mechanisms explaining subjective-objective sleep discrepancy of which 3 were supported by good-quality evidence: “Sleep being misperceived as wake”, “worry and selective attention toward sleep-related threats”, and “the presence of brief awakenings”.[27] New strategies targeting these mechanisms could possibly lead to a more efficient treatment. It appears that interventions using some form of (psycho)education have positive effects on sleep and promising effects on objective-subjective sleep discrepancy.[18; 41; 49; 53; 62] Additionally, the use of sleep restriction therapy (SRT) might be less effective in nCSP with comorbid insomnia as expected. Since our results suggest that TST tend to be underestimated in this population, the use of SRT based on self-report might reduce objective TST which could negatively impact pain given the pain-sleep interactions. Nevertheless, SRT is extremely valuable to increase sleep propensity and reduce SOL

and the number of awakenings.[55] Therefore, it seems opportune to use a modified, milder version (e.g., sleep compression). However, future studies evaluating adapted treatment strategies within people with nCSP and comorbid insomnia are necessary to confirm their effectiveness. It seems warranted to use both subjective and objective sleep assessments, to get better insight in their overall sleep. Currently, the use of actigraphy and self-report in daily clinical practice appears more realistic given its lower cost and convenience.[54] However, actigraphy should be used in combination with a sleep diary considering the limited ability to identify SOL. Additionally, considering the number of exclusions based on underlying sleep pathologies (20/146 participants), clinicians and researchers should be aware of the possibility of primary sleep pathologies. Therefore, if a primary sleep pathology is suspected or there is limited response to CBT-I, it is recommended to refer the patient to a sleep lab.

Conclusion

Findings suggest that people with nCSP and comorbid insomnia tend to underestimate TST and overestimate TIB and SOL. Clear differences, a lack of agreement and no/weak associations were found between self-reported and objectively measured sleep parameters. Future studies are necessary to confirm our results.

Acknowledgements

This study was funded by the Research Foundation Flanders - the Applied Biomedical Research (FWO-TBM, grant no. T001117N). The funding agency had no influence in the design of the study, the data collection, the analysis or the interpretation of the data and decisions regarding publication.

Conflict of interest statement

The authors have no conflicts of interest to declare.

391

References

[1] Aili K, Åström-Paulsson S, Stoetzer U, Svartengren M, Hillert L. Reliability of Actigraphy and Subjective Sleep Measurements in Adults: The Design of Sleep Assessments. J Clin Sleep Med 2017;13(1):39-47.

[2] Alsaadi SM, McAuley JH, Hush JM, Lo S, Bartlett DJ, Grunstein RR, Maher CG. The bidirectional relationship between pain intensity and sleep disturbance/quality in patients with low back pain. Clin J Pain 2014;30(9):755-765.

[3] Alsaadi SM, McAuley JH, Hush JM, Maher CG. Prevalence of sleep disturbance in patients with low back pain. Eur Spine J 2011;20(5):737-743.

[4] American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders. Washington, DC, 2013.

[5] Ancoli-Israel S, Martin JL, Blackwell T, Buenaver L, Liu L, Meltzer LJ, Sadeh A, Spira AP, Taylor DJ. The SBSM Guide to Actigraphy Monitoring: Clinical and Research Applications. Behav Sleep Med 2015;13 Suppl 1:S4-s38.

[6] Backhaus J, Junghanns K, Broocks A, Riemann D, Hohagen F. Test-retest reliability and validity of the Pittsburgh Sleep Quality Index in primary insomnia. J Psychosom Res 2002;53(3):737-740.

[7] Bahouq H, Allali F, Rkain H, Hmamouchi I, Hajjaj-Hassouni N. Prevalence and severity of insomnia in chronic low back pain patients. Rheumatol Int 2013;33(5):1277-1281.

[8] Berger AM, Wielgus KK, Young-McCaughan S, Fischer P, Farr L, Lee KA. Methodological challenges when using actigraphy in research. J Pain Symptom Manage 2008;36(2):191-199.

[9] Berry R, Brooks R, Charlene G, Harding S, Lloyd R, Quan S, Troester M, Vaughn B. The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications. Darien, IL: American Academy of Sleep Medicine, 2017.

[10] Bianchi MT, Wang W, Klerman EB. Sleep misperception in healthy adults: implications for insomnia diagnosis. J Clin Sleep Med 2012;8(5):547-554.

[11] Bilterys T, Siffain C, De Maeyer I, Van Looveren E, Mairesse O, Nijs J, Meeus M, Ickmans K, Cagnie B, Goubert D, Danneels L, Moens M, Malfliet A. Associates of Insomnia in People with Chronic Spinal Pain: A Systematic Review and Meta-Analysis. Journal of clinical medicine 2021;10(14).

[12] Bonvanie IJ, Oldehinkel AJ, Rosmalen JGM, Janssens KAM. Sleep problems and pain: a longitudinal cohort study in emerging adults. Pain 2016;157(4):957-963.

[13] Bruyneel M, Libert W, Ameye L, Ninane V. Comparison between home and hospital set-up for unattended home-based polysomnography: a prospective randomized study. Sleep Med 2015;16(11):1434-1438.

[14] Buckelmüller J, Landolt HP, Stassen HH, Achermann P. Trait-like individual differences in the human sleep electroencephalogram. Neuroscience 2006;138(1):351-356.

[15] Buysse DJ, Reynolds CF, 3rd, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry Res 1989;28(2):193-213.

[16] Castelnovo A, Ferri R, Punjabi NM, Castronovo V, Garbazza C, Zucconi M, Ferini-Strambi L, Manconi M. The paradox of paradoxical insomnia: A theoretical review towards a unifying evidence-based definition. Sleep Med Rev 2019;44:70-82.

[17] Cole RJ, Kripke DF, Gruen W, Mullaney DJ, Gillin JC. Automatic sleep/wake identification from wrist activity. Sleep 1992;15(5):461-469.

[18] Crönlein T, Lehner A, Schüssler P, Geisler P, Rupprecht R, Wetter TC. Changes in Subjective-Objective Sleep Discrepancy Following Inpatient Cognitive Behavior Therapy for Insomnia. Behav Ther 2019;50(5):994-1001.

[19] Dillon HR, Lichstein KL, Dautovich ND, Taylor DJ, Riedel BW, Bush AJ. Variability in self-reported normal sleep across the adult age span. J Gerontol B Psychol Sci Soc Sci 2015;70(1):46-56.

[20] Eadie J, van de Water AT, Lonsdale C, Tully MA, van Mechelen W, Boreham CA, Daly L, McDonough SM, Hurley DA. Physiotherapy for sleep disturbance in people with chronic low

back pain: results of a feasibility randomized controlled trial. Arch Phys Med Rehabil 2013;94(11):2083-2092.

[21] Edinger JD, Krystal AD. Subtyping primary insomnia: is sleep state misperception a distinct clinical entity? Sleep Med Rev 2003;7(3):203-214.

[22] Fejer R, Kyvik KO, Hartvigsen J. The prevalence of neck pain in the world population: a systematic critical review of the literature. Eur Spine J 2006;15(6):834-848.

[23] Fekedulegn D, Andrew ME, Shi M, Violanti JM, Knox S, Innes KE. Actigraphy-Based Assessment of Sleep Parameters. Annals of work exposures and health 2020;64(4):350-367.

[24] Geyer JD, Lichstein KL, Ruiter ME, Ward LC, Carney PR, Dillard SC. Sleep education for paradoxical insomnia. Behav Sleep Med 2011;9(4):266-272.

[25] Giavarina D. Understanding Bland Altman analysis. Biochemia medica 2015;25(2):141-151.

[26] Gore M, Tai KS, Sadosky A, Leslie D, Stacey BR. Use and costs of prescription medications and alternative treatments in patients with osteoarthritis and chronic low back pain in community-based settings. Pain practice : the official journal of World Institute of Pain 2012;12(7):550-560.

[27] Harvey AG, Tang NK. (Mis)perception of sleep in insomnia: a puzzle and a resolution. Psychol Bull 2012;138(1):77-101.

[28] Hauri PJ, Olmstead EM. Reverse first night effect in insomnia. Sleep 1989;12(2):97-105.

[29] Herrero Babiloni A, De Koninck BP, Beetz G, De Beaumont L, Martel MO, Lavigne GJ. Sleep and pain: recent insights, mechanisms, and future directions in the investigation of this relationship. Journal of neural transmission (Vienna, Austria : 1996) 2020;127(4):647-660.

[30] Hoaglin DC, Iglewicz B. Fine-Tuning Some Resistant Rules for Outlier Labeling. Journal of the American Statistical Association 1987;82(400):1147-1149.

[31] Hoy D, Bain C, Williams G, March L, Brooks P, Blyth F, Woolf A, Vos T, Buchbinder R. A systematic review of the global prevalence of low back pain. Arthritis Rheum 2012;64(6):2028-2037.

[32] Ibáñez V, Silva J, Cauli O. A survey on sleep assessment methods. PeerJ 2018;6:e4849.

[33] Jank R, Gallee A, Boeckle M, Fiegl S, Pieh C. Chronic Pain and Sleep Disorders in Primary Care. Pain research and treatment 2017;2017:9081802.

[34] Janků K, Šmotek M, Fárková E, Kopřivová J. Subjective-objective sleep discrepancy in patients with insomnia during and after cognitive behavioural therapy: An actigraphy study. J Sleep Res 2020;29(4):e13064.

[35] Kelly GA, Blake C, Power CK, O'Keeffe D, Fullen BM. The association between chronic low back pain and sleep: a systematic review. Clin J Pain 2011;27(2):169-181.

[36] Kelly RM, McDermott JH, Coogan AN. Differences in Sleep Offset Timing between Weekdays and Weekends in 79,161 Adult Participants in the UK Biobank. Clocks & sleep 2022;4(4):658-674.

[37] Lee YJ, Lee JY, Cho JH, Choi JH. Inter-rater reliability of sleep stage scoring: a meta-analysis. J Clin Sleep Med 2021.

[38] Mairesse O, MacDonald-Nethercott E, Neu D, Tellez HF, Dessy E, Neyt X, Meeusen R, Pattyn N. Preparing for Mars: human sleep and performance during a 13 month stay in Antarctica. Sleep 2019;42(1).

[39] Malfliet A, Bilterys T, Van Looveren E, Meeus M, Danneels L, Ickmans K, Cagnie B, Mairesse O, Neu D, Moens M, Goubert D, Kamper SJ, Nijs J. The added value of cognitive behavioral therapy for insomnia to current best evidence physical therapy for chronic spinal pain: protocol of a randomized controlled clinical trial. Brazilian journal of physical therapy 2019;23(1):62-70.

[40] Mathias JL, Cant ML, Burke ALJ. Sleep disturbances and sleep disorders in adults living with chronic pain: a meta-analysis. Sleep Med 2018;52:198-210.

[41] Mitchell LJ, Bisdounis L, Ballesio A, Omlin X, Kyle SD. The impact of cognitive behavioural therapy for insomnia on objective sleep parameters: A meta-analysis and systematic review. Sleep Med Rev 2019;47:90-102.

[42] Mollayeva T, Thurairajah P, Burton K, Mollayeva S, Shapiro CM, Colantonio A. The Pittsburgh sleep quality index as a screening tool for sleep dysfunction in clinical and non-clinical samples: A systematic review and meta-analysis. Sleep Med Rev 2016;25:52-73.

[43] Murray CJ, Lopez AD. Measuring the global burden of disease. N Engl J Med 2013;369(5):448-457.

[44] Murray CJ, Vos T, Lozano R, Naghavi M, Flaxman AD, Michaud C, Ezzati M, Shibuya K, Salomon JA, Abdalla S, Aboyans V, Abraham J, Ackerman I, Aggarwal R, Ahn SY, Ali MK, Alvarado M, Anderson HR, Anderson LM, Andrews KG, Atkinson C, Baddour LM, Bahalim AN, Barker-Collo S, Barrero LH, Bartels DH, Basanez MG, Baxter A, Bell ML, Benjamin EJ, Bennett D, Bernabe E, Bhalla K, Bhandari B, Bikbov B, Bin Abdulhak A, Birbeck G, Black JA, Blencowe H, Blore JD, Blyth F, Bolliger I, Bonaventure A, Boufous S, Bourne R, Boussinesq M, Braithwaite T, Brayne C, Bridgett L, Brooker S, Brooks P, Brugha TS, Bryan-Hancock C, Bucello C, Buchbinder R, Buckle G, Budke CM, Burch M, Burney P, Burstein R, Calabria B, Campbell B, Canter CE, Carabin H, Carapetis J, Carmona L, Cella C, Charlson F, Chen H, Cheng AT, Chou D, Chugh SS, Coffeng LE, Colan SD, Colquhoun S, Colson KE, Condon J, Connor MD, Cooper LT, Corriere M, Cortinovis M, de Vaccaro KC, Couser W, Cowie BC, Criqui MH, Cross M, Dabhadkar KC, Dahiya M, Dahodwala N, Damsere-Derry J, Danaei G, Davis A, De Leo D, Degenhardt L, Dellavalle R, Delossantos A, Denenberg J, Derrett S, Des Jarlais DC, Dharmaratne SD, Dherani M, Diaz-Torne C, Dolk H, Dorsey ER, Driscoll T, Duber H, Ebel B, Edmond K, Elbaz A, Ali SE, Erskine H, Erwin PJ, Espindola P, Ewoigbokhan SE, Farzadfar F, Feigin V, Felson DT, Ferrari A, Ferri CP, Fevre EM, Finucane MM, Flaxman S, Flood L, Foreman K, Forouzanfar MH, Fowkes FG, Fransen M, Freeman MK, Gabbe BJ, Gabriel SE, Gakidou E, Ganatra HA, Garcia B, Gaspari F, Gillum RF, Gmel G, Gonzalez-Medina D, Gosselin R, Grainger R, Grant B, Groeger J, Guillemin F, Gunnell D, Gupta R, Haagsma J, Hagan H, Halasa YA, Hall W, Haring D, Haro JM, Harrison JE, Havmoeller R, Hay RJ, Higashi H, Hill C, Hoen B, Hoffman H, Hotez PJ, Hoy D, Huang JJ, Ibeanusi SE, Jacobsen KH, James SL, Jarvis D, Jasrasaria R, Jayaraman S, Johns N, Jonas JB, Karthikeyan G, Kassebaum N, Kawakami N, Keren A, Khoo JP, King CH, Knowlton LM, Kobusingye O, Koranteng A, Krishnamurthi R, Laden F, Lalloo R, Laslett LL, Lathlean T, Leasher JL, Lee YY, Leigh J, Levinson D, Lim SS, Limb E, Lin JK, Lipnick M, Lipshultz SE, Liu W, Loane M, Ohno SL, Lyons R, Mabweijano J, MacIntyre MF, Malekzadeh R,

Mallinger L, Manivannan S, Marcenes W, March L, Margolis DJ, Marks GB, Marks R, Matsumori A, Matzopoulos R, Mayosi BM, McAnulty JH, McDermott MM, McGill N, McGrath J, Medina-Mora ME, Meltzer M, Mensah GA, Merriman TR, Meyer AC, Miglioli V, Miller M, Miller TR, Mitchell PB, Mock C, Mocumbi AO, Moffitt TE, Mokdad AA, Monasta L, Montico M, Moradi-Lakeh M, Moran A, Morawska L, Mori R, Murdoch ME, Mwaniki MK, Naidoo K, Nair MN, Naldi L, Narayan KM, Nelson PK, Nelson RG, Nevitt MC, Newton CR, Nolte S, Norman P, Norman R, O'Donnell M, O'Hanlon S, Olives C, Omer SB, Ortblad K, Osborne R, Ozgediz D, Page A, Pahari B, Pandian JD, Rivero AP, Patten SB, Pearce N, Padilla RP, Perez-Ruiz F, Perico N, Pesudovs K, Phillips D, Phillips MR, Pierce K, Pion S, Polanczyk GV, Polinder S, Pope CA, 3rd, Popova S, Porrini E, Pourmalek F, Prince M, Pullan RL, Ramaiah KD, Ranganathan D, Razavi H, Regan M, Rehm JT, Rein DB, Remuzzi G, Richardson K, Rivara FP, Roberts T, Robinson C, De Leon FR, Ronfani L, Room R, Rosenfeld LC, Rushton L, Sacco RL, Saha S, Sampson U, Sanchez-Riera L, Sanman E, Schwebel DC, Scott JG, Segui-Gomez M, Shahraz S, Shepard DS, Shin H, Shivakoti R, Singh D, Singh GM, Singh JA, Singleton J, Sleet DA, Sliwa K, Smith E, Smith JL, Stapelberg NJ, Steer A, Steiner T, Stolk WA, Stovner LJ, Sudfeld C, Syed S, Tamburlini G, Tavakkoli M, Taylor HR, Taylor JA, Taylor WJ, Thomas B, Thomson WM, Thurston GD, Tleyjeh IM, Tonelli M, Towbin JA, Truelsen T, Tsilimbaris MK, Ubeda C, Undurraga EA, van der Werf MJ, van Os J, Vavilala MS, Venketasubramanian N, Wang M, Wang W, Watt K, Weatherall DJ, Weinstock MA, Weintraub R, Weisskopf MG, Weissman MM, White RA, Whiteford H, Wiebe N, Wiersma ST, Wilkinson JD, Williams HC, Williams SR, Witt E, Wolfe F, Woolf AD, Wulf S, Yeh PH, Zaidi AK, Zheng ZJ, Zonies D, Lopez AD, AlMazroa MA, Memish ZA. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet 2012;380(9859):2197-2223.

[45] Nilius G, Domanski U, Schroeder M, Franke KJ, Hogrebe A, Margarit L, Stoica M, d'Ortho MP. A randomized controlled trial to validate the Alice PDX ambulatory device. Nature and science of sleep 2017;9:171-180.

[46] O'Donoghue GM, Fox N, Heneghan C, Hurley DA. Objective and subjective assessment of sleep in chronic low back pain patients compared with healthy age and gender matched controls: a pilot study. BMC Musculoskelet Disord 2009;10:122.

[47] Olfson M, Wall M, Liu SM, Morin CM, Blanco C. Insomnia and Impaired Quality of Life in the United States. J Clin Psychiatry 2018;79(5).

[48] Purushothaman B, Singh A, Lingutla K, Bhatia C, Pollock R, Krishna M. Prevalence of insomnia in patients with chronic back pain. J Orthop Surg (Hong Kong) 2013;21(1):68-70.

[49] Rezaie L, Fobian AD, McCall WV, Khazaie H. Paradoxical insomnia and subjective-objective sleep discrepancy: A review. Sleep Med Rev 2018;40:196-202.

[50] Rundo JV, Downey R, 3rd. Polysomnography. Handb Clin Neurol 2019;160:381-392.

[51] Rusterholz T, Tarokh L, Van Dongen HP, Achermann P. Interindividual differences in the dynamics of the homeostatic process are trait-like and distinct for sleep versus wakefulness. J Sleep Res 2017;26(2):171-178.

[52] Sadeh A. The role and validity of actigraphy in sleep medicine: an update. Sleep Med Rev 2011;15(4):259-267.

[53] Selvanathan J, Pham C, Nagappa M, Peng PWH, Englesakis M, Espie CA, Morin CM, Chung F. Cognitive behavioral therapy for insomnia in patients with chronic pain - A systematic review and meta-analysis of randomized controlled trials. Sleep Med Rev 2021;60:101460.

[54] Smith MT, McCrae CS, Cheung J, Martin JL, Harrod CG, Heald JL, Carden KA. Use of Actigraphy for the Evaluation of Sleep Disorders and Circadian Rhythm Sleep-Wake Disorders: An American Academy of Sleep Medicine Systematic Review, Meta-Analysis, and GRADE Assessment. J Clin Sleep Med 2018;14(7):1209-1230.

[55] Spielman AJ, Yang C-M, Glovinsky PB. Chapter 1 - Sleep Restriction Therapy. In: M Perlis, M Aloia, B Kuhn, editors. Behavioral Treatments for Sleep Disorders. San Diego: Academic Press, 2011. pp. 9-19.

[56] Sribastav SS, Peiheng H, Jun L, Zemin L, Fuxin W, Jianru W, Hui L, Hua W, Zhaomin Z. Interplay among pain intensity, sleep disturbance and emotion in patients with non-specific low back pain. PeerJ 2017;5:e3282.

[57] St-Jean G, Turcotte I, Bastien CH. Cerebral asymmetry in insomnia sufferers. Front Neurol 2012;3:47.

[58] Stone JD, Rentz LE, Forsey J, Ramadan J, Markwald RR, Finomore VS, Galster SM, Rezai A, Hagen JA. Evaluations of Commercial Sleep Technologies for Objective Monitoring During Routine Sleeping Conditions. Nature and science of sleep 2020;12:821-842.

[59] Tang NK. Insomnia Co-Occurring with Chronic Pain: Clinical Features, Interaction, Assessments and Possible Interventions. Reviews in pain 2008;2(1):2-7.

[60] Tang NK, Harvey AG. Correcting distorted perception of sleep in insomnia: a novel behavioural experiment? Behav Res Ther 2004;42(1):27-39.

[61] Tang NK, Wright KJ, Salkovskis PM. Prevalence and correlates of clinical insomnia co-occurring with chronic back pain. J Sleep Res 2007;16(1):85-95.

[62] Trauer JM, Qian MY, Doyle JS, Rajaratnam SM, Cunnington D. Cognitive Behavioral Therapy for Chronic Insomnia: A Systematic Review and Meta-analysis. Ann Intern Med 2015;163(3):191-204.

[63] Trimmel K, Eder HG, Böck M, Stefanic-Kejik A, Klösch G, Seidel S. The (mis)perception of sleep: factors influencing the discrepancy between self-reported and objective sleep parameters. J Clin Sleep Med 2021;17(5):917-924.

[64] Tucker AM, Dinges DF, Van Dongen HP. Trait interindividual differences in the sleep physiology of healthy young adults. J Sleep Res 2007;16(2):170-180.

[65] van de Water AT, Eadie J, Hurley DA. Investigation of sleep disturbance in chronic low back pain: an age- and gender-matched case-control study over a 7-night period. Man Ther 2011;16(6):550-556.

[66] Van de Water AT, Holmes A, Hurley DA. Objective measurements of sleep for non-laboratory settings as alternatives to polysomnography--a systematic review. J Sleep Res 2011;20(1 Pt 2):183-200.

[67] Van Looveren E, Bilterys T, Munneke W, Cagnie B, Ickmans K, Mairesse O, Malfliet A, De Baets L, Nijs J, Goubert D. The Association between Sleep and Chronic Spinal Pain: A Systematic Review from the Last Decade. Journal of clinical medicine 2021;10(17):3836.

612

613

FIGURES LEGENDS

FIGURE 1. Study flowchart

FIGURE 2. Bland and Altman plot for Pittsburgh Sleep Quality Index and polysomnography data

Bland and Altman plot for Pittsburgh Sleep Quality Index and polysomnography data, with the mean and 95% confidence interval (3 full lines), the limits of agreement (large, dotted line) and the 24%-difference limits (small, dotted line). Abbreviations: psg, polysomnography; q, questionnaire; SE, Sleep efficiency; SOL, Sleep Onset Latency; TIB, Time In Bed; TST, Total Sleep Time.

FIGURE 3. Bland and Altman plot for Pittsburgh Sleep Quality Index and actigraphy data

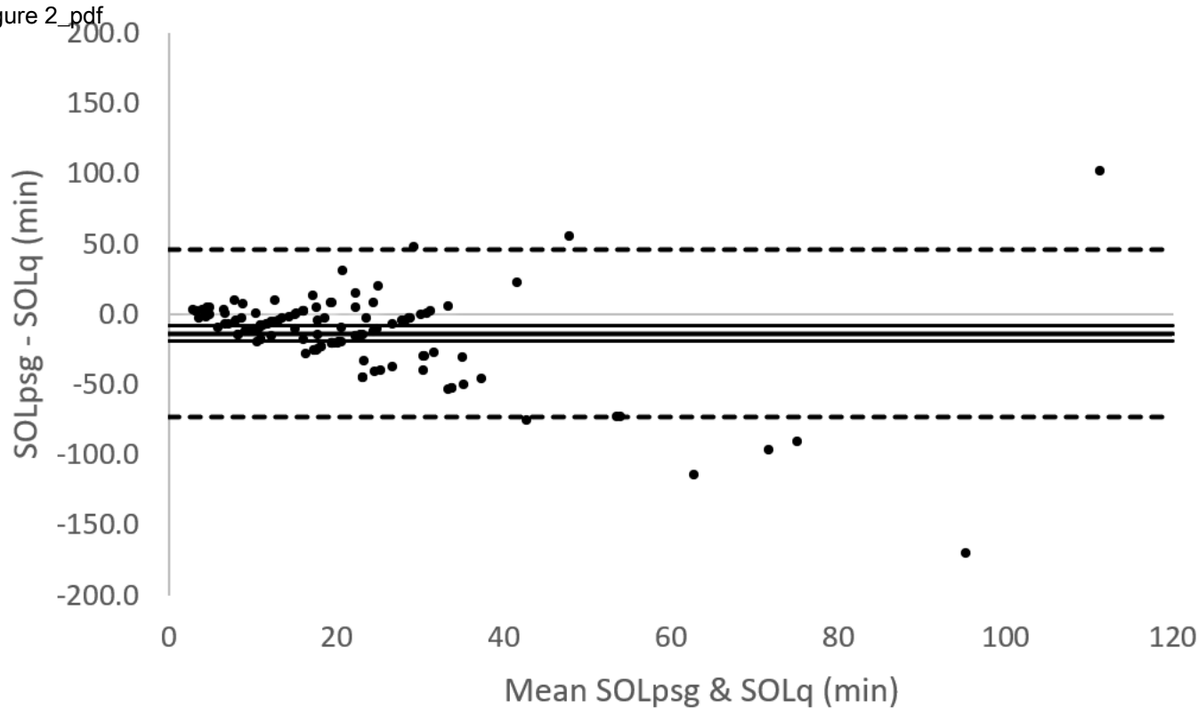
Bland and Altman plot for Pittsburgh Sleep Quality Index and actigraphy data, with the mean and 95% confidence interval (3 full lines), the limits of agreement (large, dotted line) and the 24%-difference limits (small, dotted line). Abbreviations: a, actigraphy; q, questionnaire; SE, Sleep efficiency; TIB, Time In Bed; TST, Total Sleep Time.

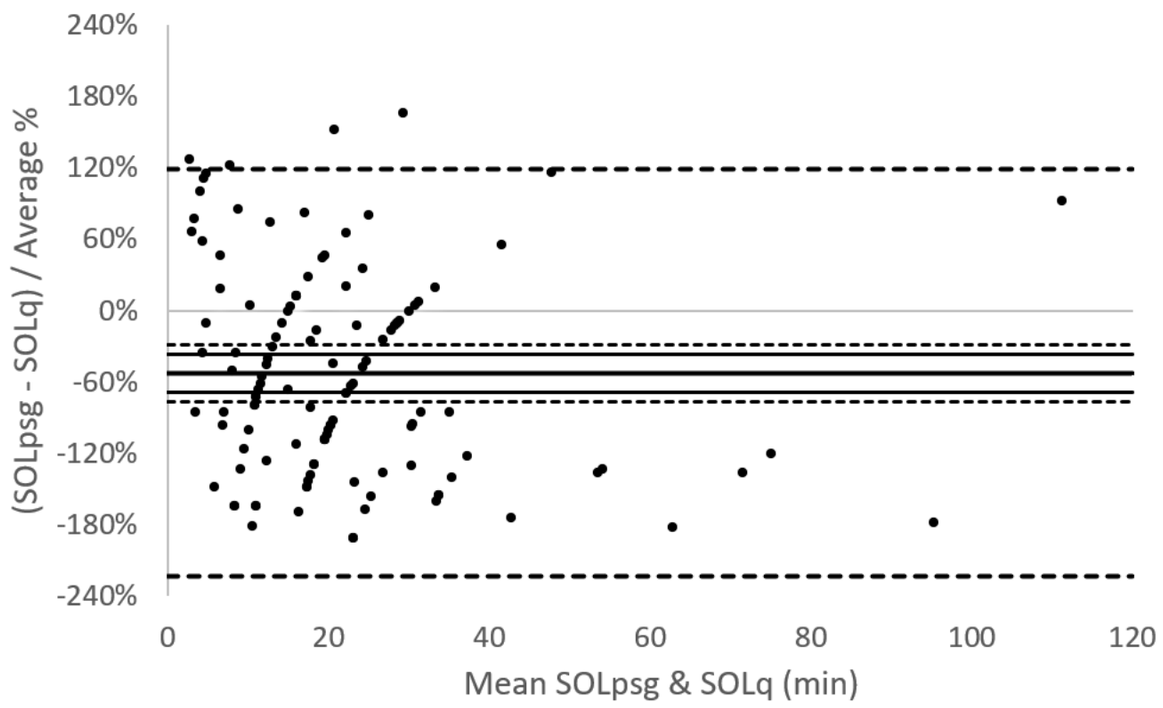
FIGURE 4. Bland and Altman plot for actigraphy and polysomnography data

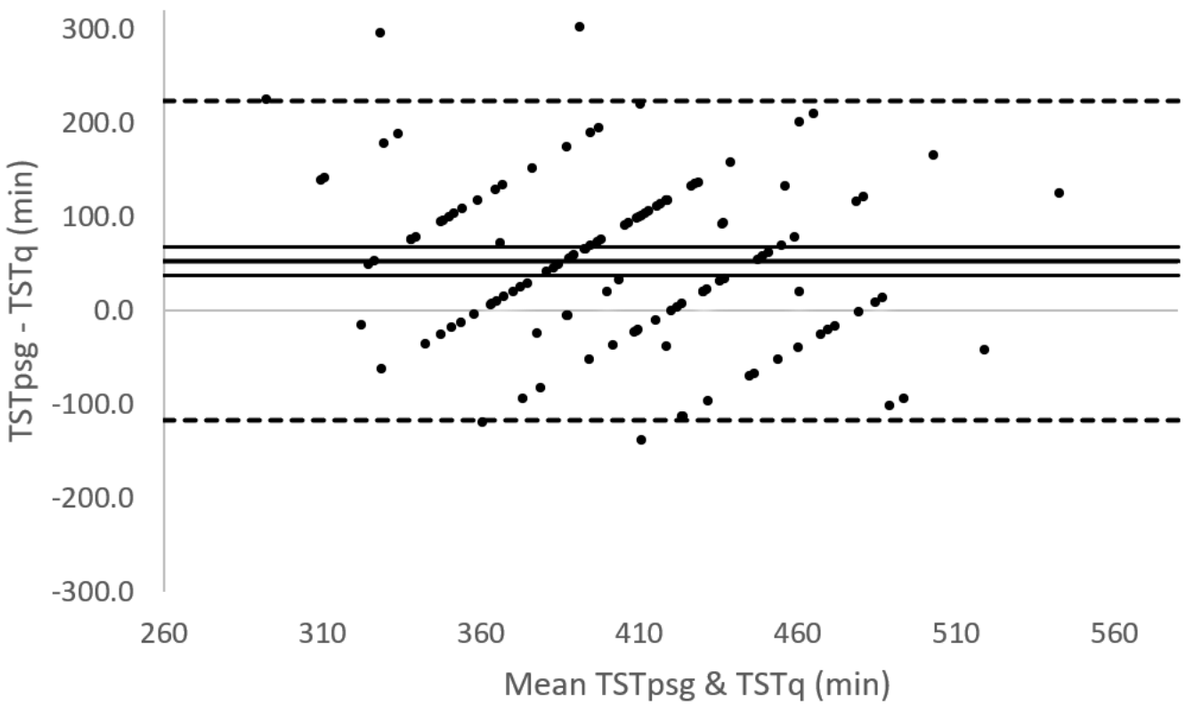
Bland and Altman plot for actigraphy and polysomnography data, with the mean and 95% confidence interval (3 full lines), the limits of agreement (large, dotted line) and the 24%-difference limits (small, dotted line). Abbreviations: a, actigraphy; psg, polysomnography; SE, Sleep efficiency; TIB, Time In Bed; TST, Total Sleep Time; WASO, Wake After Sleep Onset.

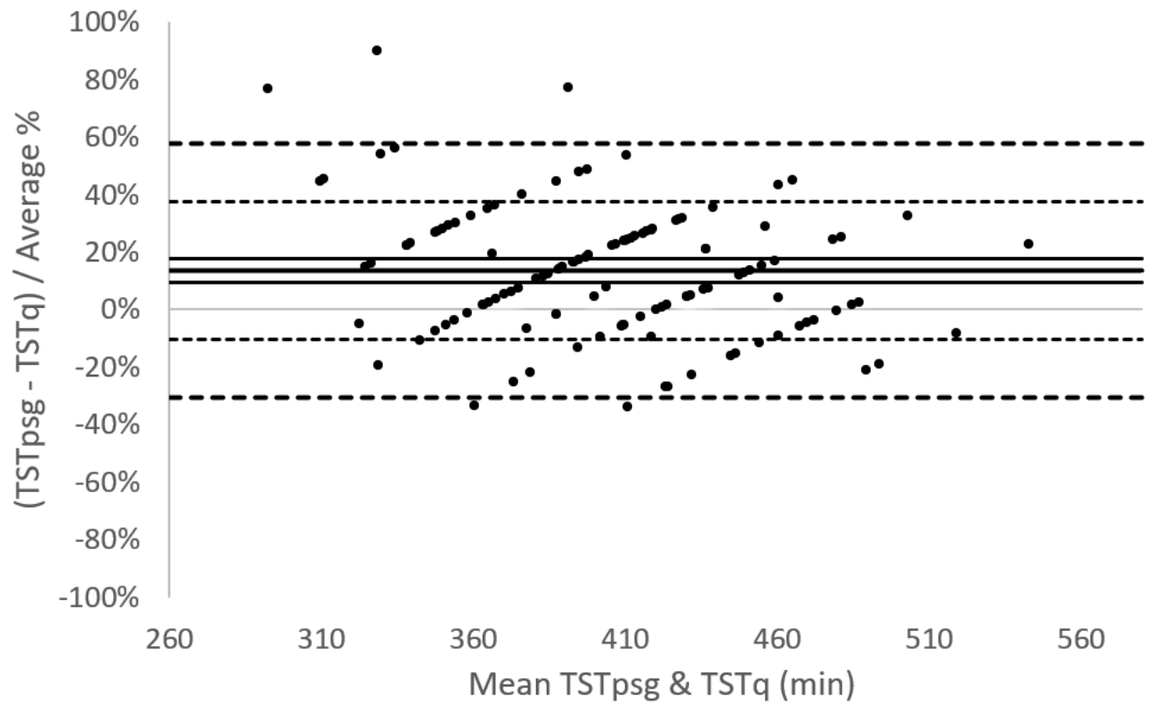
Objective-subjective sleep differences vary across people with chronic spinal pain and comorbid insomnia but overall they tend to underestimate total sleep time.

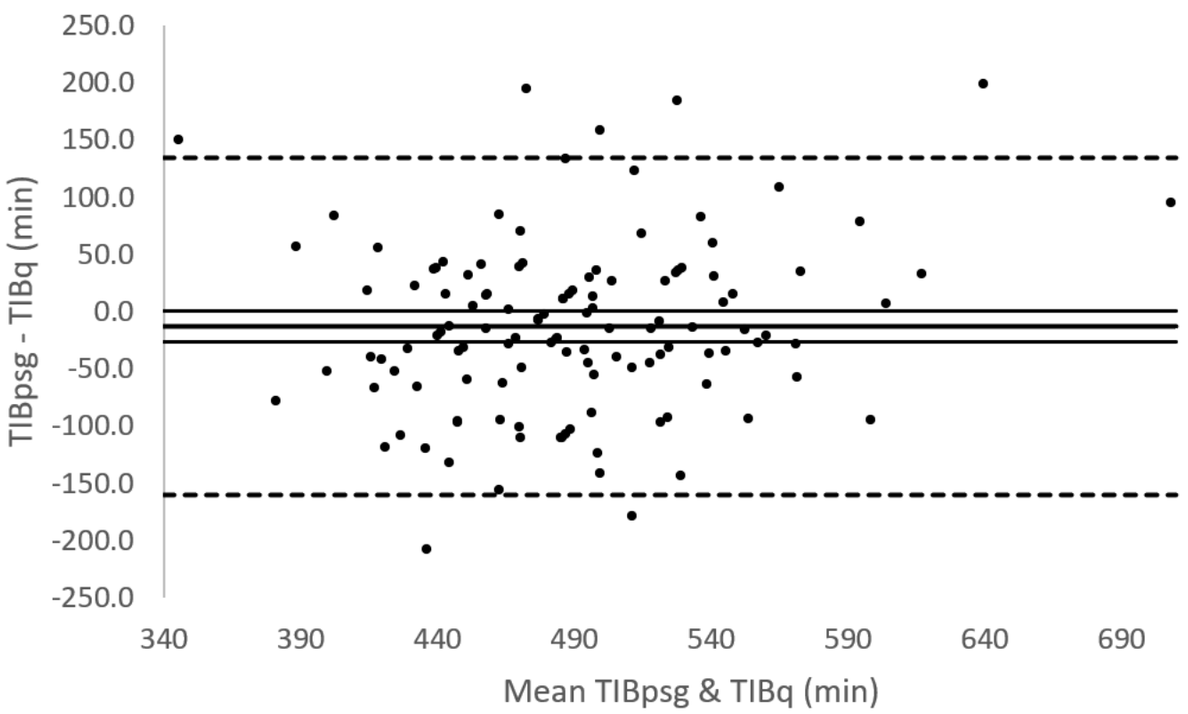
Figure 2_pdf

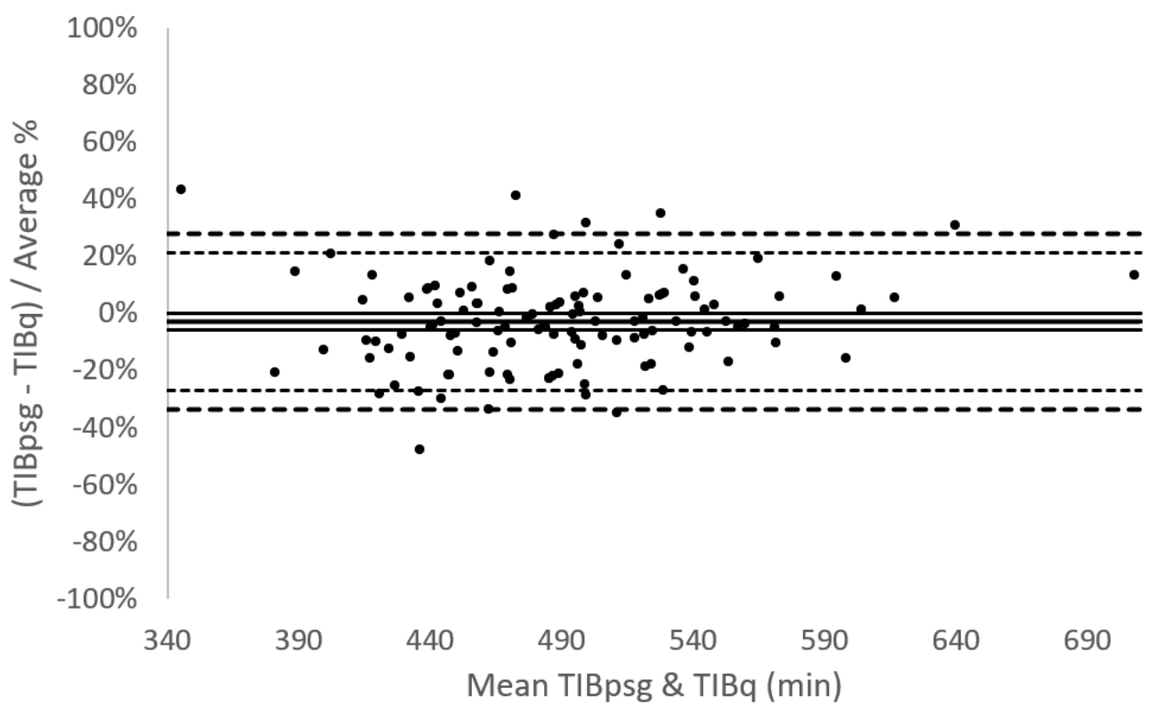

SOLpsg - SOLq (min)
Mean SOLpsg & SOLq (min)

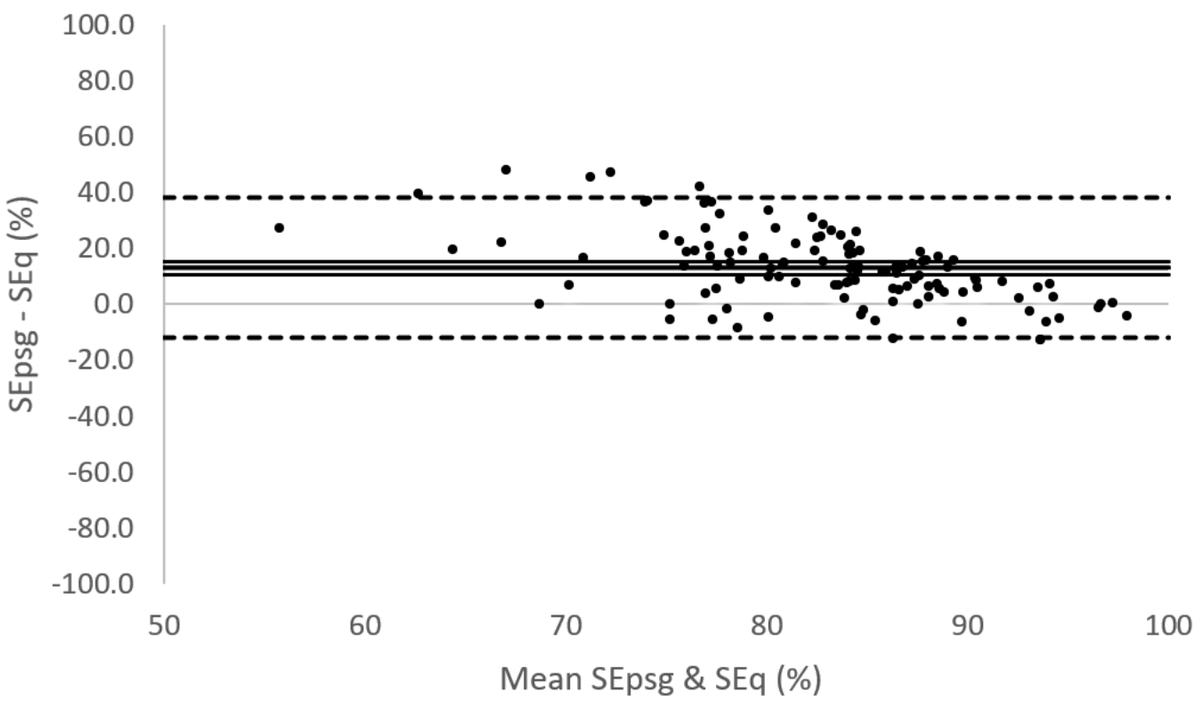

(SOLpsg - SOLq) / Average %
Mean SOLpsg & SOLq (min)


TSTpsg - TSTq (min)
Mean TSTpsg & TSTq (min)


(TSTpsg - TSTq) / Average %
Mean TSTpsg & TSTq (min)


TIBpsg - TIBq (min)
Mean TIBpsg & TIBq (min)


(TIBpsg - TIBq) / Average %
Mean TIBpsg & TIBq (min)


SEpsg - SEq (%)
Mean SEpsg & SEq (%)

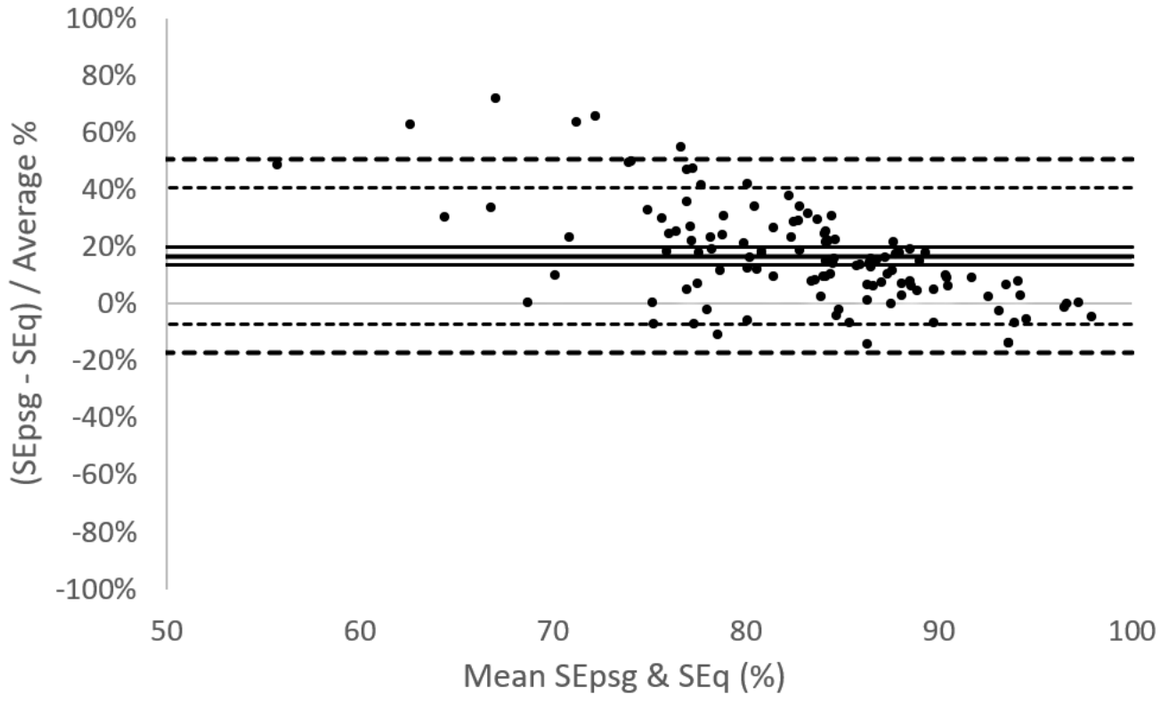
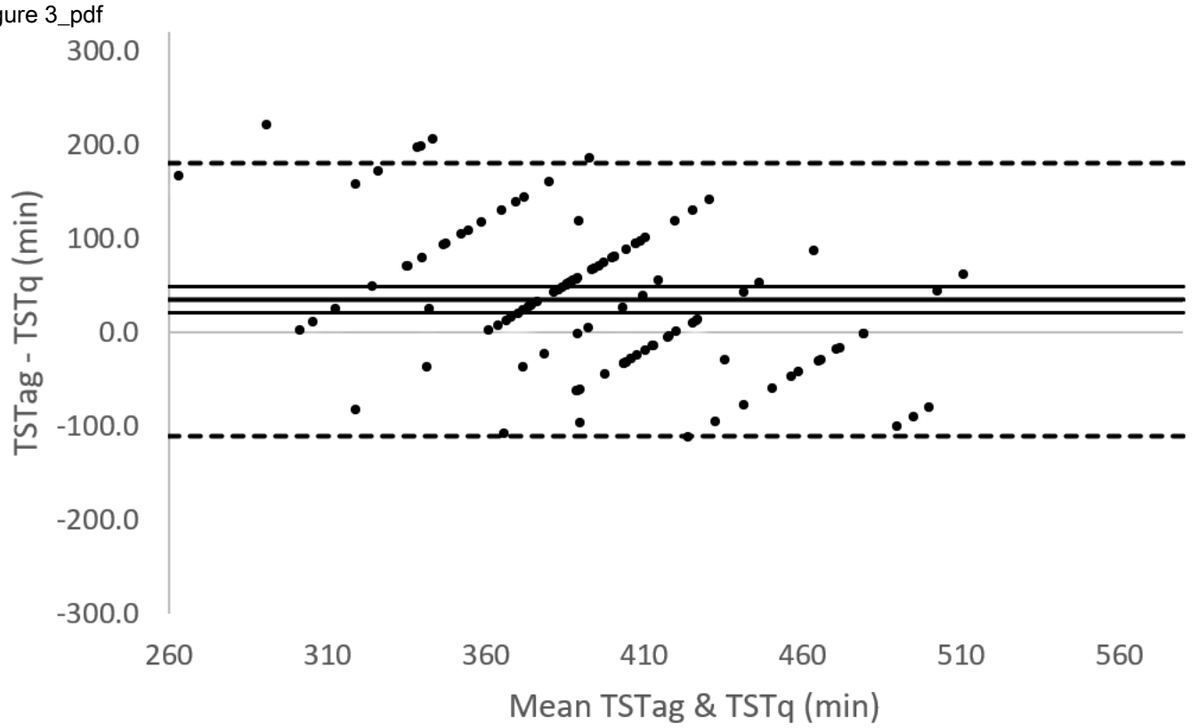
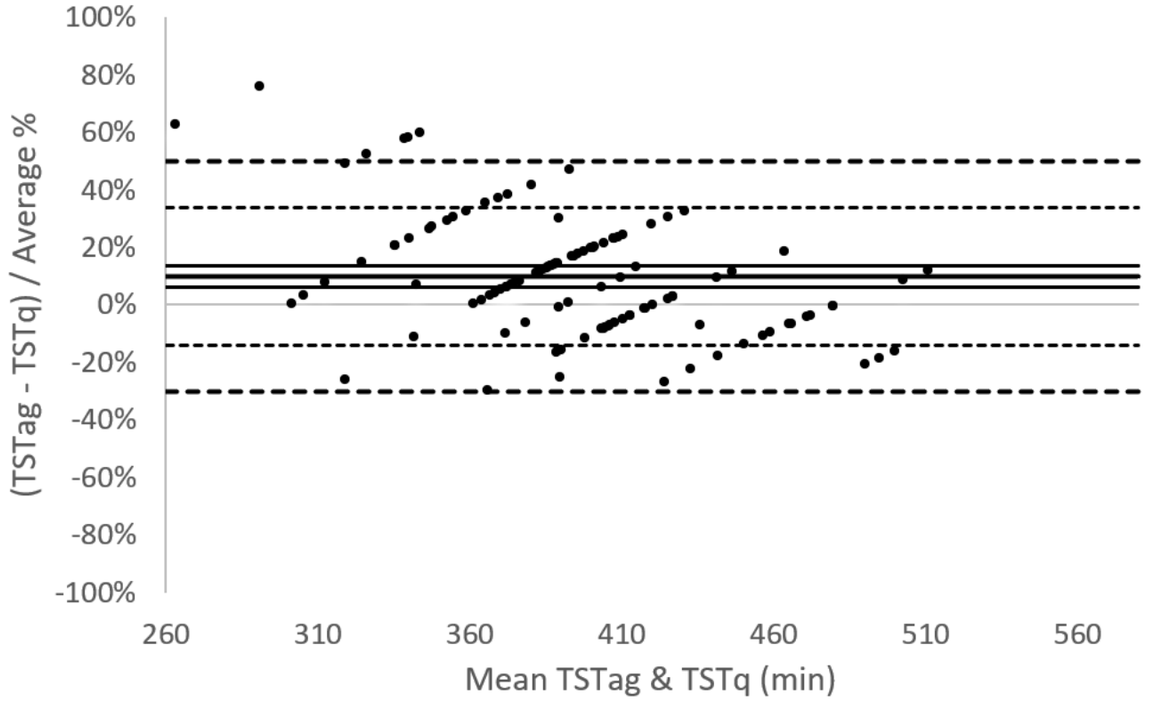
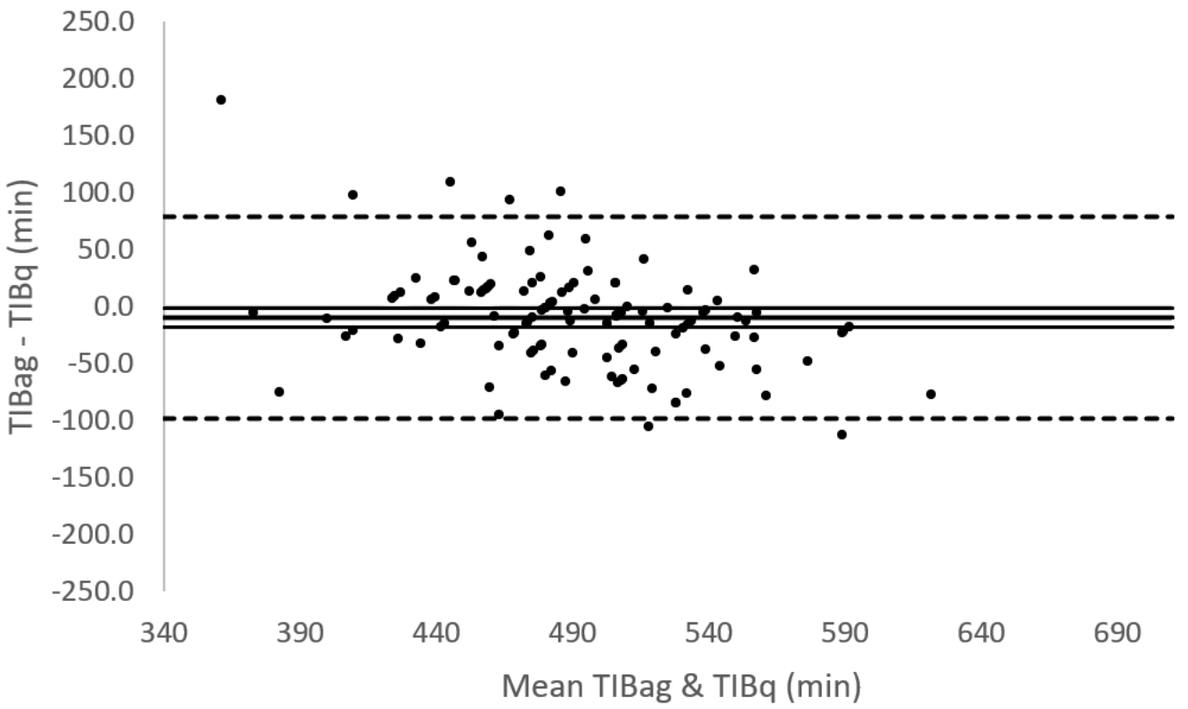
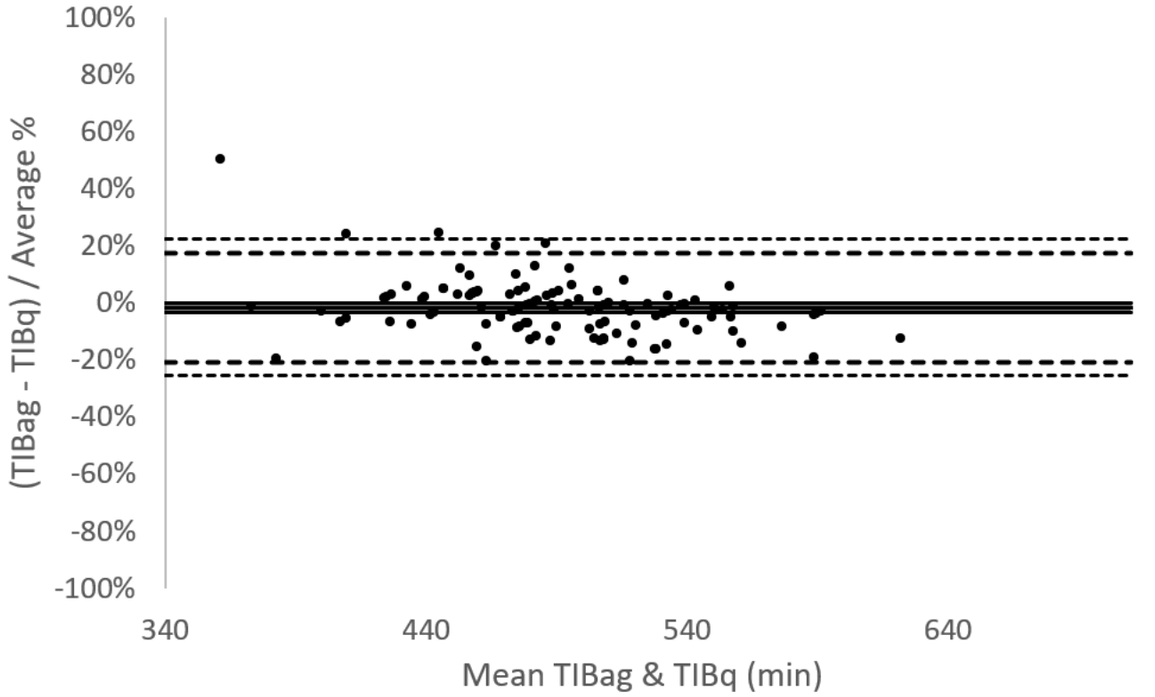

(SEpsg - SEq) / Average %
Mean SEpsg & SEq (%)

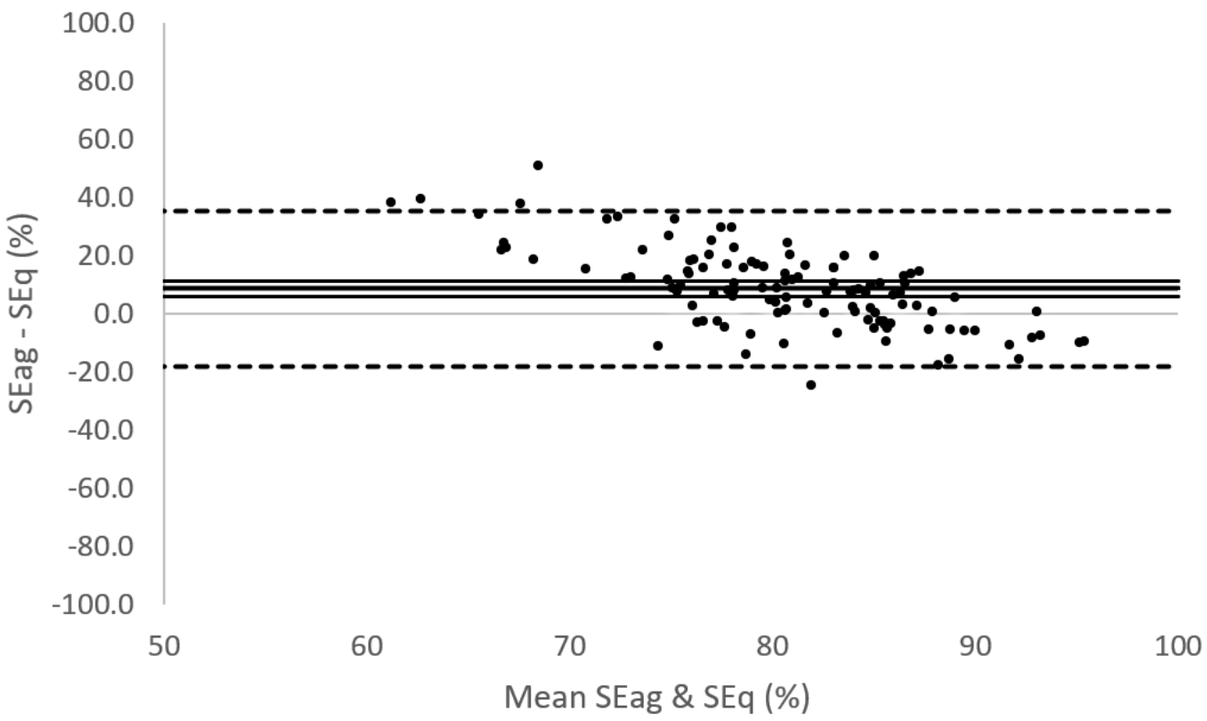
Figure 3_pdf


300.0
200.0
100.0
0.0
-100.0
-200.0
-300.0
TSTag - TSTq (min)
260
310
360
410
460
510
560
Mean TSTag & TSTq (min)


100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
(TSTag - TSTq) / Average %
260
310
360
410
460
510
560
Mean TSTag & TSTq (min)


250.0
200.0
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
-200.0
-250.0
TIBag - TIBq (min)
340
390
440
490
540
590
640
690
Mean TIBag & TIBq (min)


100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
(TIBag - TIBq) / Average %
340
440
540
640
Mean TIBag & TIBq (min)


100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
SEag - SEq (%)
50
60
70
80
90
100
Mean SEag & SEq (%)

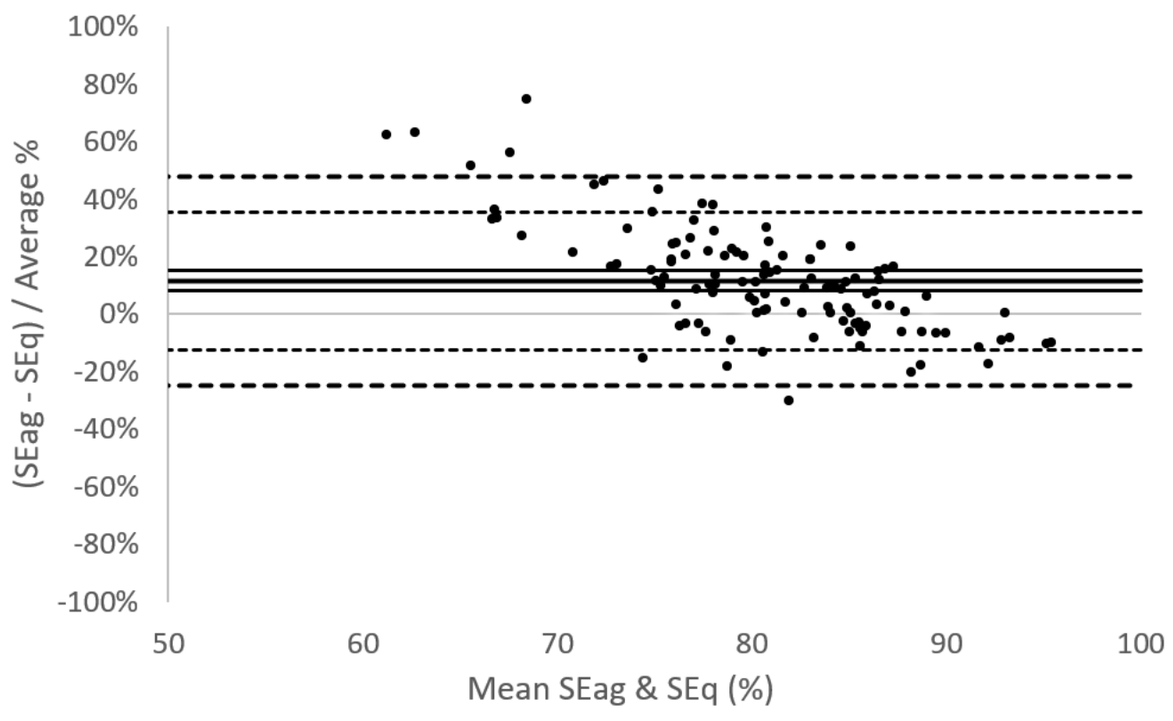
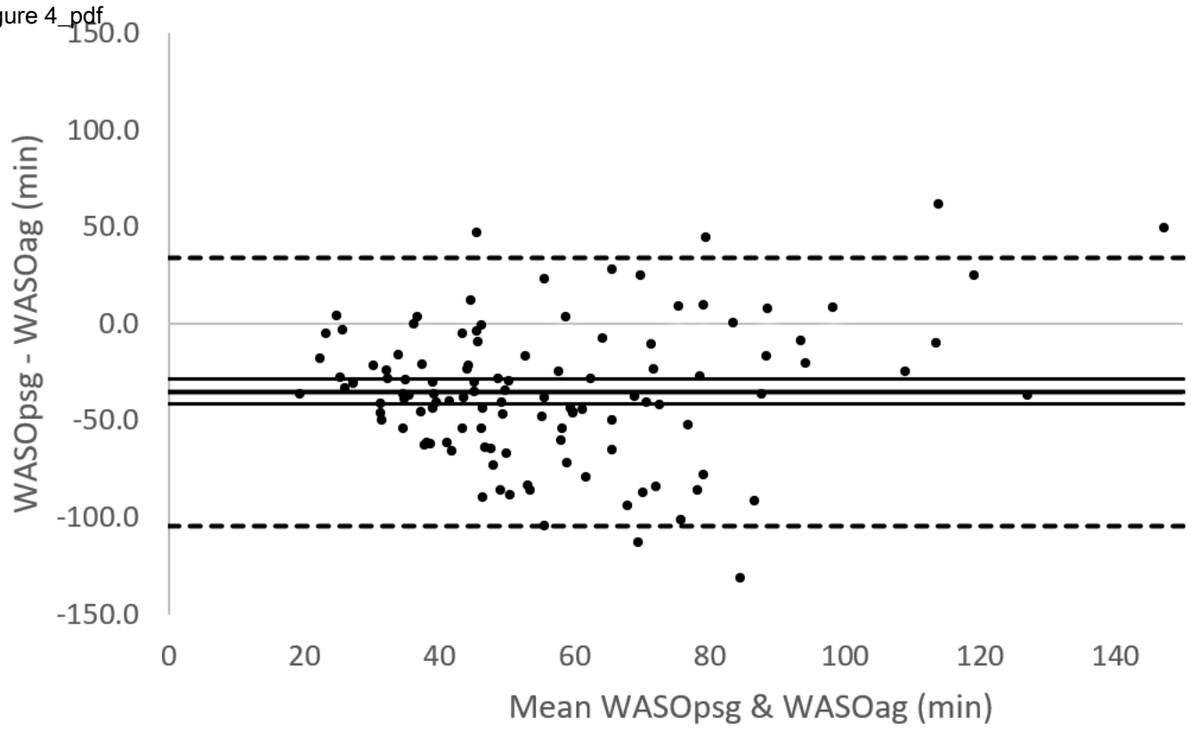
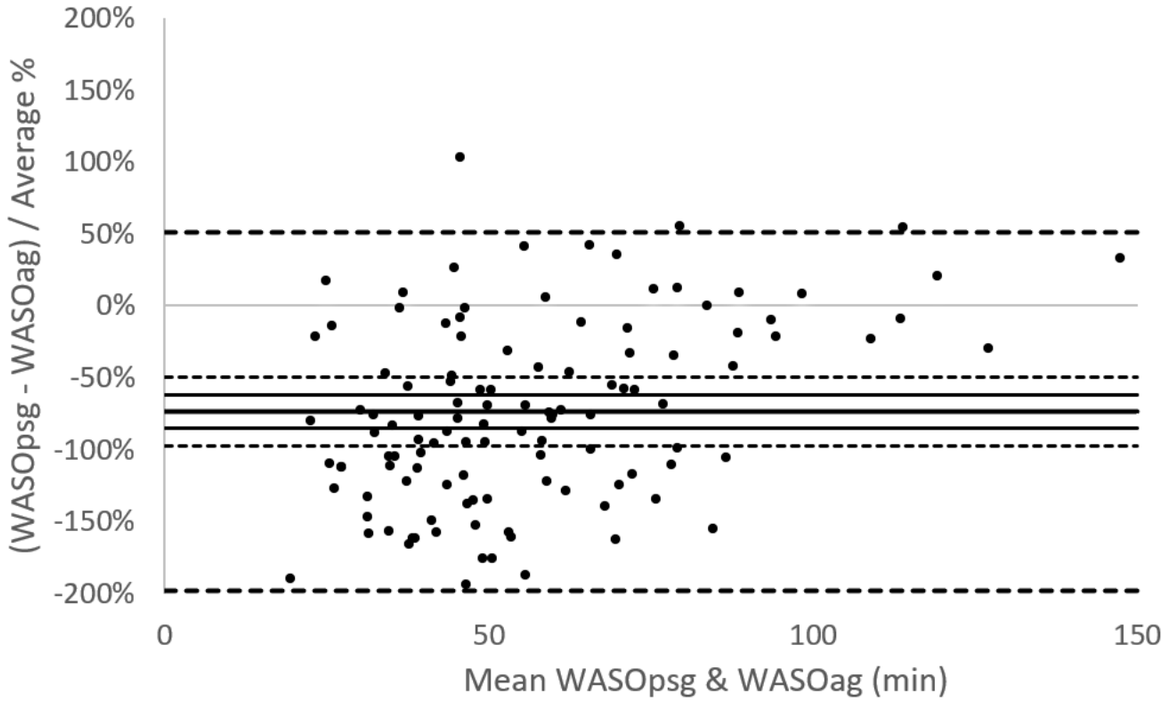
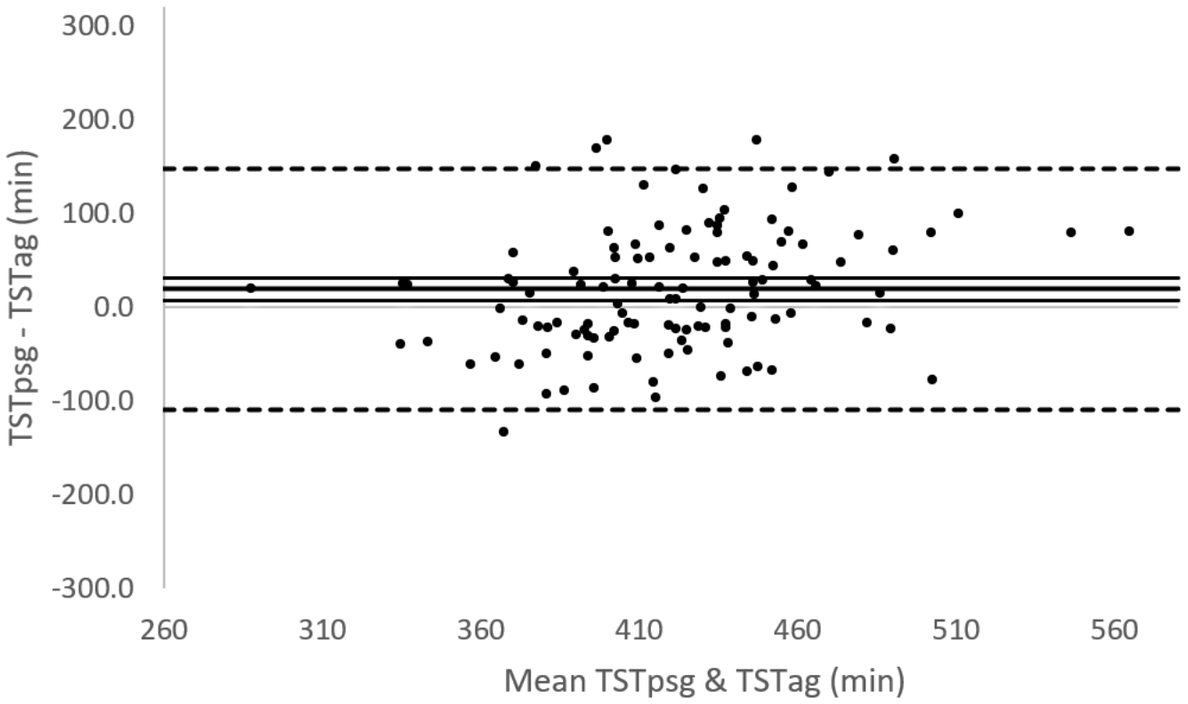
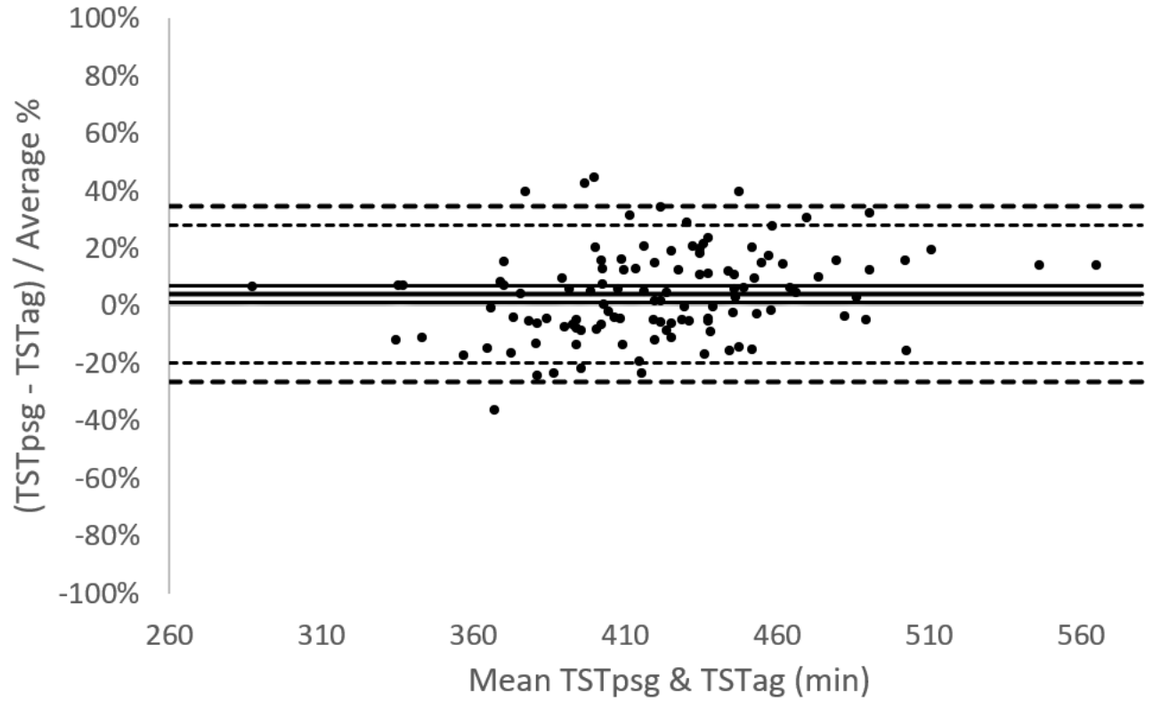

100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
(SEag - SEq) / Average %
50
60
70
80
90
100
Mean SEag & SEq (%)

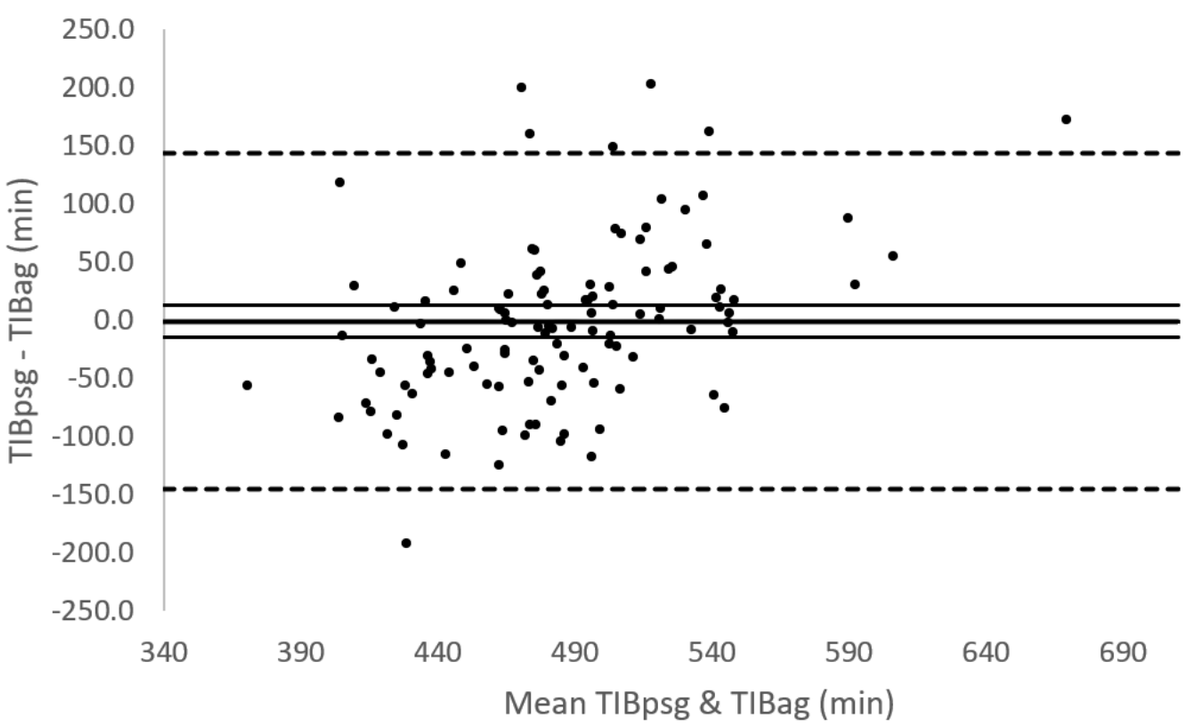
Figure 4_pdf

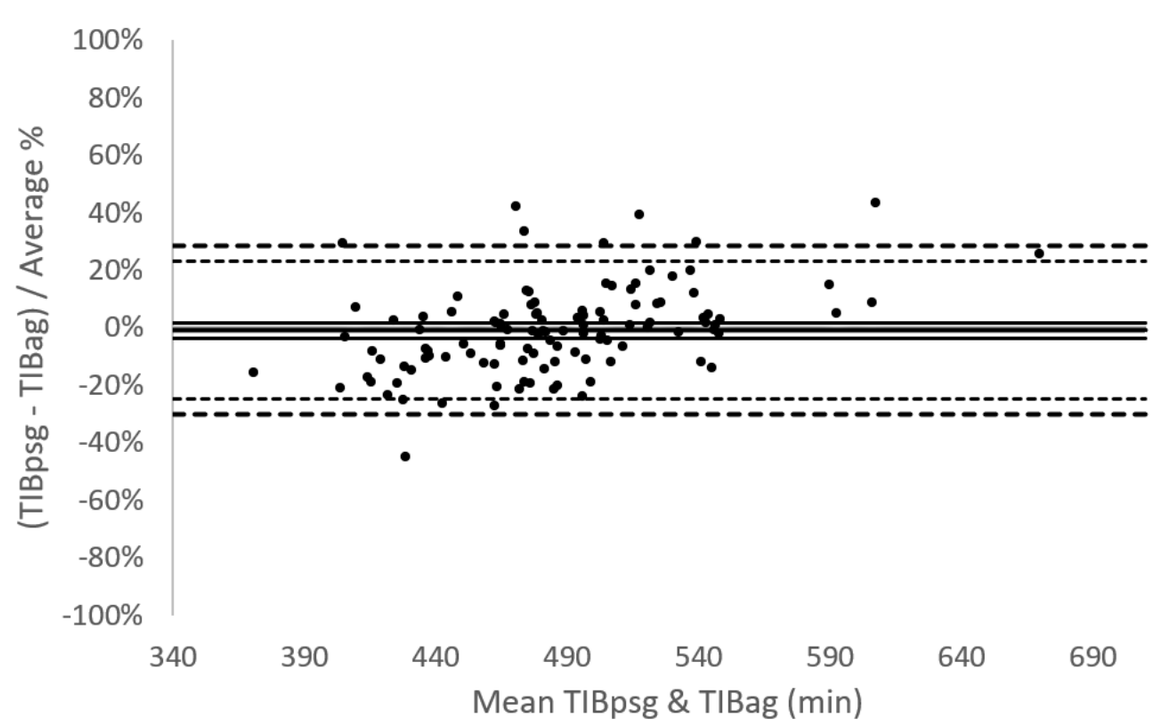

150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
WASOpsg - WASOag (min)
0
20
40
60
80
100
120
140
Mean WASOpsg & WASOag (min)

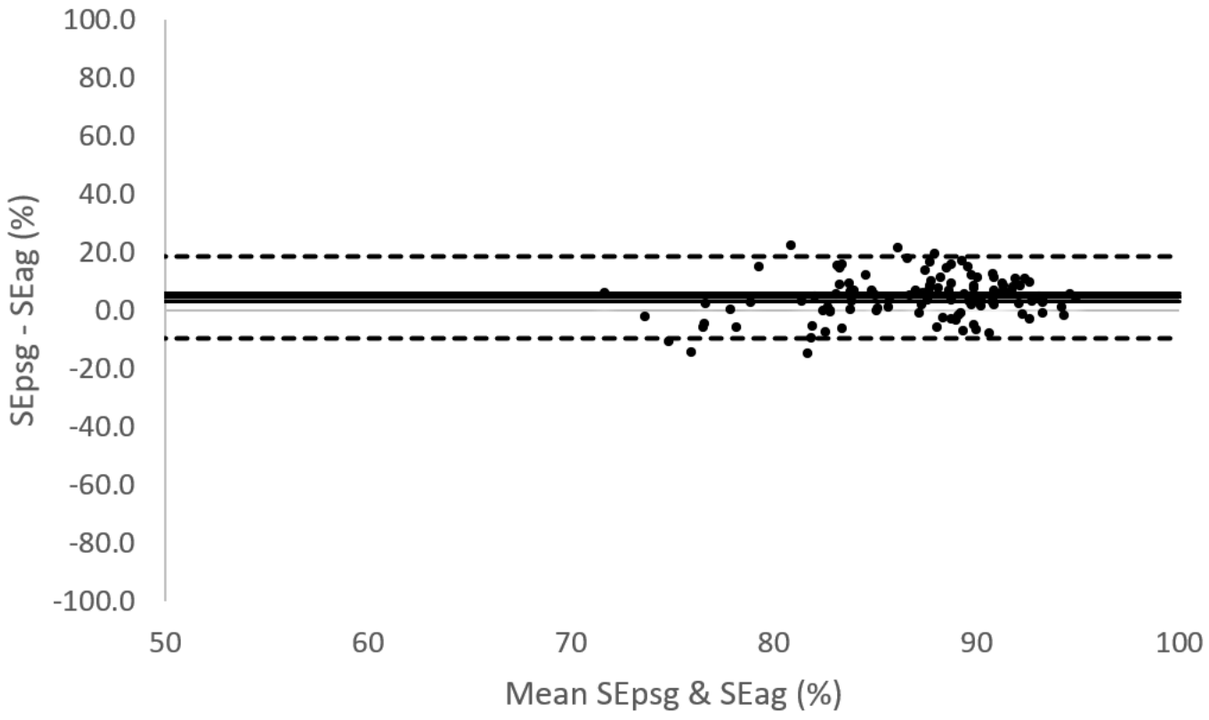

200%
150%
100%
50%
0%
-50%
-100%
-150%
-200%
(WASOpsg - WASOag) / Average %
0
50
100
150
Mean WASOpsg & WASOag (min)


300.0
200.0
100.0
0.0
-100.0
-200.0
-300.0
TSTpsg - TSTag (min)
260
310
360
410
460
510
560
Mean TSTpsg & TSTag (min)


100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
(TSTpsg - TSTag) / Average %
260
310
360
410
460
510
560
Mean TSTpsg & TSTag (min)


250.0
200.0
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
-200.0
-250.0
TIBpsg - TIBag (min)
340
390
440
490
540
590
640
690
Mean TIBpsg & TIBag (min)


100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
(TIBpsg - TIBag) / Average %
340
390
440
490
540
590
640
690
Mean TIBpsg & TIBag (min)


100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
SEpsg - SEag (%)
50
60
70
80
90
100
Mean SEpsg & SEag (%)

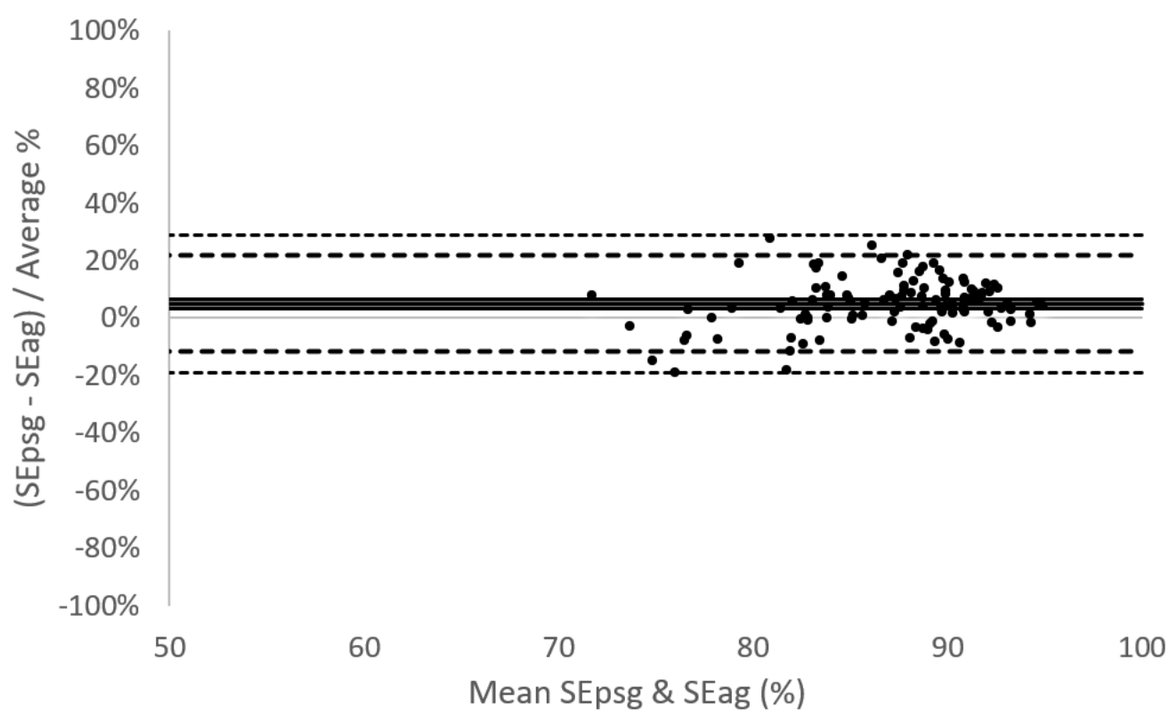

100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
(SEpsg - SEag) / Average %
50
60
70
80
90
100
Mean SEpsg & SEag (%)

Table 1

TABLE 1. Demographics and baseline characteristics of investigated sample of patients with nCSP and comorbid insomnia (n=123).

Demographic characteristics	n	Mean	Standard Deviation	Range
Demographics				
Sex,[a] F/M	123	84/39		
Dominant pain region,[a] neck pain/back pain	123	71/52		
Duration of pain, mo	123	89.08	95.90	3 – 540
Age, y	123	40.20	11.18	21 – 61
BMI	123	23.32	3.14	16 - 30
Level of education[a]	123			
- Lower secondary		1		
- Higher Secondary		22		
- Higher professional education		3		
- Professional bachelor		40		
- Academic bachelor		7		
- Master		49		
- Doctorate		1		
Baseline characteristics				
BPI – Mean pain severity questions	123	4.39	1.52	0.50 – 8.25
BPI – Mean pain interference questions	123	3.13	1.81	0 – 7.71
CSI	123	43.53	10.69	16 – 70
ISI	123	15.13	4.13	4 – 27
PSQI	123	9.47	2.71	4 – 16
BFS – Mental fatigue	123	3.19	2.51	0 – 10
BFS – Physical Fatigue	123	3.33	2.16	0 – 9
ESS	123	8.24	4.65	0 – 22
HADS - Anxiety	123	8.76	3.61	1 – 18
HADS - Depression	123	5.15	3.29	0 – 15
SF-36 Physical functioning	123	70.24	17.91	35 – 100
SF-36 Role physical functioning	123	51.63	39.69	0 – 100
SF-36 Role emotional functioning	123	68.29	40.46	0 – 100
SF-36 Energy / fatigue	123	51.02	16.84	5 – 85
SF-36 Emotional well-being	123	63.90	15.71	24 – 96
SF-36 Social functioning	123	71.75	21.70	0 – 100
SF-36 Pain	123	54.70	17.50	10 – 90
SF-36 General Health	123	55.12	16.77	15 – 95
Sleep parameters (Questionnaire – PSG – AG)				
Questionnaire PSQI	123			
- SOL (minutes)		28.87	26.70	1.00 – 180.00
- TST (minutes)		377.44	69.57	180.00 – 540.00
- TIB (minutes)		495.67	60.64	270.00 – 660.00
- SE (%)		76.34	12.14	42.10 – 100.00
Home-based PSG	122			
- SOL (minutes)		14.85	17.79	1.00 – 162.50
- WASO (minutes)		37.91	31.34	1.00 – 172.00
- EMA (minutes)		5.39	8.44	.00 – 59.00
- TST (minutes)		429.96	60.03	297.00 – 605.00
- TIB (minutes)		482.71	71.62	332.00 – 755.50
- SE (%)		89.41	6.62	68.80 – 97.80
Actigraphy	116			
- WASO (minutes)		73.94	27.26	22.00 – 150.00
- TST (minutes)		411.64	45.55	278.00 – 541.00
- TIB (minutes)		485.59	44.00	345.00 – 583.00
- SE (%)		84.85	5.44	69.00 – 95.00

F: female; M: male; mo: months; y: years; BPI: Brief Pain Inventory; CSI: Central Sensitization Inventory; ISI: Insomnia Severity Index; PSQI: The Pittsburgh Sleep Quality Index; BFS: Brugmann Fatigue Scale; ESS: Epworth sleepiness scale; HADS: Hospital Anxiety and Depression Scale; SF-36: 36-Item Short Form Survey; PSG: Polysomnography; AG: Actigraphy; SOL: Sleep Onset Latency; TST: Total Sleep Time; TIB: Time In Bed; SE: Sleep Efficiency; WASO: Wake After Sleep Onset; EMA; Early Morning Awakening.

[a] Categorical data presented as frequencies.

TABLE 2. Associations between subjective sleep parameters (Pittsburgh Sleep Quality Index) and objective sleep parameters (polysomnography) in people with nonspecific chronic spinal pain and comorbid insomnia.

Pittsburgh Sleep Quality Index – Polysomnography (n=122)		
Sleep parameters	**Pearson correlation coefficient**	**P value**
SOL	.113	.216
TST	.112	.219
TIB	.365	<.001
SE	.175	.054

SOL: Sleep Onset Latency; TST: Total Sleep Time; TIB: Time In Bed; SE: Sleep Efficiency; WASO: Wake After Sleep Onset.

TABLE 3. Associations between a actigraphy sleep parameter and sleep parameters measured by self-report (Pittsburgh Sleep Quality Index) or polysomnography in people with nonspecific chronic spinal pain and comorbid insomnia.

Pittsburgh Sleep Quality Index – Actigraphy (n=116)		
Sleep parameters	**Pearson correlation coefficient**	**P value**
SOL	NA*	NA*
TST	.243	.009
TIB	.667	<.001
SE	-.004	.965
Actigraphy – Polysomnography (n=116)		
Sleep parameters	**Pearson correlation coefficient**	**P value**
SOL	NA*	NA*
WASO	.296	.001
TST	.271	.003
TIB	.281	.002
SE	.299	.001

SOL: Sleep Onset Latency; TST: Total Sleep Time; TIB: Time In Bed; SE: Sleep Efficiency; WASO: Wake After Sleep Onset; NA: Not applicable.

**No SOL values were identified based on the actigraphy data*

Table 4

TABLE 4. Difference between the subjective sleep parameter (Pittsburgh Sleep Quality Index) and objective sleep parameters (polysomnography) in people with nonspecific chronic spinal pain and comorbid insomnia (n=122)**.**

Pittsburgh Sleep Quality Index versus polysomnography						
		Questionnaire	Polysomnography			
Sleep parameter	n	Mean (SD)	Mean (SD)	Mean Difference [95% CI]	t	p value
SOL (minutes)	122	28.61 (26.65)	14.85 (17.79)	-13.76 [-19.20, -8.33]	-5.014	<.001
TST (minutes)	122	377.58 (69.83)	429.95 (60.03)	52.37 [36.81, 67.94]	6.662	<.001
TIB (minutes)	122	495.80 (60.87)	482.71 (71.62)	-13.08 [-26.56, .39]	-1.922	.057
SE (%)	122	76,36 (12,19)	89.41 (6.62)	13.05 [10.76, 15.35]	11.253	<.001
SOL: Sleep Onset Latency; TST: Total Sleep Time; TIB: Time In Bed; SE: Sleep Efficiency; WASO: Wake After Sleep Onset.						

Table 5

TABLE 5. Difference between the subjective sleep parameter (Pittsburgh Sleep Quality Index) and objective sleep parameters (polysomnography and actigraphy) in people with nonspecific chronic spinal pain and comorbid insomnia (n=123).

Pittsburgh Sleep Quality Index versus actigraphy						
		Questionnaire	Actigraphy			
Sleep parameter	N	Mean (SD)	Mean (SD)	Mean Difference [95% CI]	t	p value
SOL (minutes)	122	28.61 (26.65)	NA*	NA*	NA*	NA*
TST (minutes)	116	377.44 (69.57)	419.00 (36.24)	34.44 [20.83, 48.06]	5.011	<.001
TIB (minutes)	116	495.54 (60.20)	485.59 (44.00)	-9.95 [-18.23, -1.67]	-2.382	.019
SE (%)	116	76.31 (12.42)	84.85 (5.44)	8.54 [6.04, 11.03]	6.773	<.001
Actigraphy versus polysomnography						
		Actigraphy	Polysomnography			
Sleep parameter	n	Mean (SD)	Mean (SD)	Mean Difference [95% CI]	t	p value
SOL (minutes)	122	NA*	14.85 (17.79)	NA*	NA*	NA*
WASO (minutes)	116	73.94 (27.26)	38.66 (31.84)	-35.28 [-41.76, -28.80]	-10.778	<.001
TST (minutes)	116	411.64 (45.55)	430.46 (60.91)	18.82 [6.79, 30.85]	3.098	.002
TIB (minutes)	116	485.59 (44.00)	484.13 (72.80)	-1.46 [-15.02, 12.10]	-.213	.831
SE (%)	116	84.85 (5.44)	89.27 (6.70)	4.41 [3.08, 5.75]	6.550	<.001

SOL: Sleep Onset Latency; TST: Total Sleep Time; TIB: Time In Bed; SE: Sleep Efficiency; WASO: Wake After Sleep Onset; NA: not applicable.

**No SOL values were identified based on the actigraphy data*

Fig

Enrollment & Screening

Enrolled patients with chronic spinal pain and comorbid insomnia (n=146)

Patients excluded after PSG screening (n=20)
- Apnea-hypopnea index > 15 (n=17)
- Periodic leg movement (n=3)

Patients eligible after PSG screening (n=126)

Additional exclusions (n=3)
- Recent spinal surgery (n=2)
- Widespread pain (n=1)

Patients eligible for participation (n=123)

Assessment & missing data

Assessments including online questionnaires, actigraphy and home-based polysomnography (n=123)

Online questionnaires (n=123)	Actigraphy (n=116)	Polysomnography (n=122)
- No missing data	- Defect actigraph monitor (n=1) - Corrupted datafile (n=2) - Data could not be downloaded from monitor (n=4)	- Refusal to participate in polysomnography assessment (n=1)

Analyses

Analyses of objective and subjective sleep parameters using data from participants (including correlation analysis, t-test, and Blant Altmant plots)

- Analyses using data from online questionnaires and actigraphy data (n=116)
- Analyses using data from online questionnaires and polysomnography data (n=122)
- Analyses using actigraphy data and polysomnography data (n=116)