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Leg actigraphy to quantify periodic limb movements of sleep: a systematic review and meta-analysis

David T. Plante[1]

[1]Department of Psychiatry, University of Wisconsin School of Medicine and Public Health, Madison, WI, USA

SUMMARY

Periodic limb movements of sleep (PLMS) are repetitive, stereotyped movements that can disrupt sleep and result in insomnia, non-restorative sleep, and/or daytime sleepiness. Currently, polysomnography is the gold standard and only clinically acceptable means of quantifying PLMS. Leg-worn actigraphy is an alternative method of measuring PLMS, which may circumvent many of the economic and technical limitations of polysomnography to quantify nocturnal leg movements. However, the use of leg actigraphy as a diagnostic means of assessing PLMS has not been systematically evaluated. In this review, the use of leg-worn actigraphy to measure PLMS is systematically evaluated, using both qualitative and quantitative assessment. Findings demonstrate significant heterogeneity among a limited number of studies in terms of type of actigraph utilized, position of the device on the lower extremity, and methods employed to count PLMS. In general, common accelerometers vary in their sensitivity and specificity to detect PLMS, which is likely related to the technical specifications of a given device. A current limitation in the ability to combine data from actigraphs placed on both legs is also a significant barrier to their use in clinical settings. Further research is required to determine the optimal methods to quantify PLMS using leg actigraphy, as well as specific clinical situations in which these devices may prove most useful.

Keywords

leg actigraphy; leg accelerometry; pam-rl; actiwatch; periodic limb movements; polysomnography

INTRODUCTION

Actigraphy, which involves the use of a non-invasive portable device to track movement, is a valuable tool in the clinical practice of Sleep Medicine. The vast majority of research on

Corresponding Author: David T. Plante, M.D., Wisconsin Psychiatric Institute and Clinics, 6001 Research Park Blvd., Madison, WI 53719, dplante@wisc.edu, (608)-232-3323, (608)-231-9011 (fax).

actigraphy has focused on wrist-worn devices that track rest-activity patterns, serving as a surrogate measure for periods of sleep and wakefulness. These devices provide acceptably accurate estimates of sleep and wake in healthy populations, as well as in disorders characterized by insomnia and/or hypersomnia, including circadian rhythm disorders [1, 2]. In addition, actigraphy often provides useful data in assessing the response to therapy across many of these disorders [1, 2].

Recent years have seen significant shifts in the practice of clinical Sleep Medicine, primarily driven by the ascension of home sleep testing as a viable alternative to in-laboratory polysomnography in the diagnosis of obstructive sleep apnea (OSA) [3]. Out-of-center testing for sleep disorders has the potential benefits of improving delivery of care to patients and decreasing economic costs. Relative to the level of research that has been devoted to the validation of portable monitoring devices to diagnose sleep-related breathing disorders, the use of actigraphy to quantify periodic limb movements of sleep (PLMS), which are repetitive, stereotyped movements that can disrupt sleep and result in insomnia, non-restorative sleep, and/or daytime sleepiness, has received relatively little attention.

The use of actigraphy to measure PLMS has several potential advantages over the current reference standard of polysomnography. Leg actigraphy can provide assessment of limb movements over multiple nights, which may circumvent the diagnostic difficulties associated with high night-to-night variability of PLMS frequency [4]. Also, actigraphy is utilized in the home setting, which may decrease confounding environmental factors (e.g. use of nicotine/alcohol; irregular sleep-wake patterns) that may cause in-laboratory testing to be a poor reflection of the patient's typical experience. Finally, despite the absence of a formal economic analysis, the cost of actigraphy to quantify PLMS is likely to be substantially less than in-laboratory polysomnography, even if repeated over multiple nights to increase diagnostic yield.

The use of actigraphy worn on the lower extremities to measure periodic limb movements has been utilized in large-scale studies to confirm the presence of PLMS [5], and as a measure of treatment response in restless legs syndrome (RLS) [6, 7]. However, despite individual studies that have examined the validity of lower extremity actigraphy to detect PLMS, the aggregate evidence for leg actigraphy to quantify PLMS has not been systematically evaluated. Such an empiric evaluation is necessary as it may provide valuable insights into the clinical utility of leg actigraphy, and highlight areas in which further research is required before such devices can be considered standard of care. Thus, the primary objective of this systematic review was to analyze the current literature regarding the validity of lower extremity-worn actigraphy in the quantification of PLMS against the gold standard of polysomnography.

METHODS

Criteria for considering studies of this review

Types of participants—Studies that included patients or research subjects who were evaluated with reason to suspect possible periodic limb movements of sleep were included. Studies evaluating both adults and children were included because there is currently no

difference in the polysomnographic scoring of PLMS between children and adults according to standard guidelines [8, 9].

Forms of interventions—The index test was leg worn actigraphy and the reference (gold) standard was electromyography (EMG) as part of polysomnography to quantify PLMS. Because there are multiple makes and models of actigraphy that have been used in prior studies, type of device was not a limitation on study consideration for inclusion/exclusion, unless the device in question utilized a form of movement sensor other than an accelerometer. Minimal standards to define polysomnography for this study included measures of neurophysiologic activity (electroencephalogram; EEG), eye movements (electrooculogram), and leg electromyography (EMG).

Outcome measures—The outcome measures of interest were the periodic limb movement index (PLMI; number of periodic limb movements per hour of sleep/recording) and/or total periodic limb movement (PLM) counts derived by simultaneous polysomnography and leg actigraphy, respectively.

Types of studies—All comparison-based studies that examined the use of actigraphy/accelerometry worn on the lower extremities on the same night as a polysomnographic recording were considered. Studies were included that reported comparisons between polysomnographic and actigraphic PLMI and/or total PLM counts, even if this was not a primary aim of the study (e.g., a randomized-controlled trial of a pharmacologic treatment would be included, as long as data regarding polysomnography and leg actigraphy from the same night were reported).

Search strategy—Searches were conducted using the following databases: Pubmed, Web of Knowledge, CINHAL Plus, Compendex, and PsychINFO, as well as “waterfall” and “ancestral” searches of related materials. There were no limitations on year of publication or language of article. The following terms were utilized for searches: pam-rl OR leg actigraph* OR limb actigraph* OR leg acceleromet* OR limb acceleromet* AND polysomnogra*. Both peer reviewed publications and unpublished literature (meeting abstracts, dissertations/theses, etc.) were included, since the likelihood of unpublished studies, and thus publication bias, is higher in studies of diagnostic tests [10]. The author conducted all searches. The last search was performed July 7, 2013.

Eligibility—The following criteria were required for inclusion: 1) simultaneous collection of leg actigraphy and polysomnography with report of PLMI and/or total number of PLM derived from each measure and/or report of relationship between these variables (e.g. correlation); and 2) study of human participants. Specific placement of the actigraphic device could vary across studies (e.g., ankle vs. mid-calf placement), as could type of actigraph, however, these factors were considered in the qualitative and quantitative analysis of the data (see Analysis). Exclusion criteria included: 1) absence of simultaneous polysomnography and leg actigraphy; 2) use of non-human subjects or simulation-based data; 3) failure to report PLMI/PLM counts from polysomnography and/or leg actigraphy or their correlative relationship; and 4) use of out-of-center measurement device to determine

PLMI other than actigraphy (e.g., mattress pressure sensor). All articles were screened for inclusion by the author, unblinded to manuscript authorship.

Data Extraction—The author extracted all data (unblinded). Extracted data included: author/journal, year of publication, type of study, make/model of actigraphy, actigraphy settings, placement of device (e.g. single leg vs. bilateral; ankle vs. dorsum of foot), method for calculating PLMI, number and demographics (ages, sex, co-morbid disorders, etc.) of subjects, findings (e.g., sensitivity, specificity), cut-off point used in dichotomous testing to define a clinically significant number of PLMS (e.g. PLMI>5, 10, 15/hr), and level of evidence (Table 1). Level of evidence was determined by the primary author according to the Centre for Evidence Based Medicine (CEBM) guidelines for diagnostic studies [11].

Assessment of study quality—Study quality was assessed (unblinded) by the author using the standards of the Quality Assessment of Diagnostic Accuracy Studies, version 2 (QUADAS-2) [12]. Ratings of each study using QUADAS-2 are presented as a resource/reference to the reader, but were not used in the weighting of quantitative data (see Analysis).

Analysis—All studies that met inclusion/exclusion criteria were analyzed in the qualitative assessment of the literature on this topic. In addition, studies that reported two by two contingency tables for a single PLMI threshold and/or sufficient data to produce such tables (e.g. PLMI derived from actigraphy and polysomnography for each subject) were considered for meta-analysis. Attempts were made by the author to contact authors of studies who did not report sufficient data for meta-analysis, but would otherwise qualify for inclusion. Meta-analysis was performed using Meta-DiSc Software, a freely available software package for meta-analysis of diagnostic studies [13]. The primary outcomes of interest for meta-analysis were sensitivity and specificity, with heterogeneity of studies (and thus appropriateness of data pooling) assessed using the diagnostic odds ratio (a measure for the discriminative power of a diagnostic test that considers both sensitivity and specificity). Meta-analysis was performed using random-effects model (DerSimonian-Laird). It was anticipated *a priori* that likely confounders that would affect meta-analysis could include type of actigraphy device, placement/position, PLMI threshold, and/or patient demographics/diagnoses. In addition, because preliminary searches had identified manuscripts demonstrating significant limitations of studies that did not utilize data from both legs simultaneously to quantify PLMS [14], studies that reported values for a single leg or analyzed each leg separately were excluded from meta-analysis.

RESULTS

Study Inclusion and Assessment

The Preferred Reporting Items for Systematic Reviews (PRISMA)[15] flow diagram is presented in Figure 1. After duplicates were removed, database and other searches identified 472 possible records, which were subsequently screened for inclusion/exclusion. Reasons full-text articles were excluded are enumerated in Figure 1. One study was published in Czech [16] and the article was translated using Google Translate (http://

translate.google.com); otherwise, all articles were published in English. Fourteen studies met inclusion/exclusion criteria for qualitative review [14, 16–28], and five [14, 16, 22, 24, 26] met inclusion criteria for quantitative meta-analysis (Figure 1).

QUADAS-2 ratings are presented in supplementary Figure S1, Table S1. In terms of risk of bias, it was notably common among studies to not report whether the sample was drawn from a consecutive and/or random sample versus a sample of convenience. Additionally, details regarding whether PLMS were scored blind to reference polysomnography were frequently omitted from manuscripts.

Qualitative Synthesis

Overall, leg actigraphy showed variable efficacy in quantifying periodic limb movements across studies. Several factors likely contributed to different results among studies including variation in models and placement of actigraphs on the lower extremities, PLMI cut-offs used to define clinically significant PLMS, and methods used to calculate PLMI.

Several different leg actigraphs were utilized in the studies included in this review, with the majority using either the Actiwatch and/or PAM-RL (Table 1). The PAM-RL has been placed exclusively on the ankle (as it was designed), with variability in the use of bilateral or single limbs to determine PLMI. The Actiwatch has been typically placed either on the dorsum of the foot or the ankle, again, with variability regarding unilateral or bilateral placement and evaluation of data (Table 1).

Earlier studies reported the use of other leg actigraphs including Movoport [17], Swiss-type [21], or Kick Counter [20]. These earlier prototype devices were only studied on one limb, and despite statistically significant correlations between PLMI derived by actigraphy and polysomnography (r=0.78–0.91), they had a tendency to underestimate the PLMI [21]. Moreover, these devices are no longer commercially available, making them unlikely to be a pragmatic means of quantifying PLMI for the practicing clinician.

The strong correlation between polysomnography and actigraphy-derived PLMI using these older devices, however, underscores the necessity that further data be reported to substantiate the ability of leg actigraphy to accurately quantify PLMS. A high correlation does not equate with good agreement between two methods of measurement, as correlations can be spurious due to a wide spread sample and/or outliers in the data. Thus, it would be more ideal for studies to report sufficient information to construct the diagnostic two by two contingency table with its four cells (true positives, false negative, false positives, and true negatives), so the diagnostic capabilities of leg actigraphy can be more fully ascertained [29]. Five of the fourteen identified studies were reported in abstract form [18–20, 23, 27], with results reported as correlative [19, 20], proportion of agreement between individual limb movement counts by PSG and actigraphy [18], and/or presented with insufficient detail to fully interpret the results of these studies in the evaluation of leg actigraphy as an assessment tool for PLMS compared to polysomnography [23, 27].

When a diagnostic test has a continuous outcome, such as the PLMI, the threshold used to construct two by two contingency tables is also an important factor in evaluating the

literature [29]. In the case of leg actigraphy, there are a wide range of PLMI cut-offs that have been utilized, however the most common has been five per hour (5/hr) (Table 1). Notably, many studies report sensitivities and specificities for multiple PLMI cut-offs within the same study, with 10/hr and/or 15/hr being the other most common thresholds (Table 1). However, higher cut-offs (25/hr, 50/hr) that are infrequently used clinically, have also been reported [24]. Further complicating the literature are reports that construct two by two tables using cut-points for PLMI that differ between actigraphy and polysomnography, which makes comparison to other studies difficult [23].

There is also variability among investigators regarding the calculation of PLMI using total recording time or sleep time (Table 1). This is important because several investigators noted that leg actigraphy tended to overestimate PLMS when sleep efficiency (determined using EEG-defined sleep) was low [17, 22, 27]. Various approaches and/or correction factors have been applied to improve the congruency between actigraphy and polysomnography-derived limb movements such as inclusion of leg movements occurring during arousals and/or periods of wakefulness [14, 16, 25, 26], and the use of sleep time derived from PSG-defined sleep periods rather than time in bed to calculate actigraphic PLMI [28]. The latter strategy may improve accuracy of leg-worn actigraphy in the context of a research endeavor, but would not be pragmatic in real-world contexts as it obviates the benefits of actigraphy if simultaneous polysomnography is required for accurate PLMI determination. The former strategy is likely of greater clinical utility, however, it highlights variability of scoring standards for periodic limb movements during wake, which are delineated in the current World Association of Sleep Medicine (WASM) standards [30], but not the guidelines of the American Academy of Sleep Medicine (AASM) [9].

Like increased wake-time during a recording, sleep disordered breathing can also lead to overestimates of PLMI using leg actigraphy since current scoring rules discount a leg movement that occurs as a consequence of a respiratory event [9, 22]. This has been dealt with differently across studies, with investigators either scoring limb movements independent of respiratory signals [24], or including limb movements associated with respiratory events in the scoring of PLMS [16, 26]. Other studies have focused largely on subjects with sleep-related movement disorders, which may have limited the number of patients with clinically significant OSA, however the presence or absence of co-occurring sleep disordered breathing has been variably reported in such investigations [17–20].

The majority of studies, particularly those published within the last decade, collected data using bilateral leg actigraphy. There was variability in how data from both limbs was utilized in analyses. Many studies combined data from each leg into the same time series [14, 16, 22–24, 26]. One study further utilized bilateral leg data in two different placements (dorsum of foot and ankle) using the same type of actigraph (Actiwatch) during a single recording night [26]. Two studies, both in pediatric populations, collected data from both limbs and analyzed them separately [25, 28]. In studies that reported data either from a single limb or in each limb separately, there was a lack of consensus regarding which limb was used for analysis. Rogers et al., chose to analyze data from the dominant limb after initial investigation demonstrated strongest correlations between PLMI derived by polysomnography and actigraphy in the this leg [28]. Montgomery-Downs et al, reported

data for the right and left leg separately [25]. Several reports did not specify which leg was used [18, 20, 27], while other reports focused exclusively on the right foot [17, 21].

One study compared the PAM-RL and Actiwatch in the same patients, however, only a subset of 10 out of 24 patients had both types of leg actigraphy on the same night [14]. This study noted that the PAM-RL tended to overestimate, while the Actiwatch tended to underestimate, the PLMI relative to PSG. The authors also noted that the PLMI was highly variable depending on which threshold settings were used for PAM-RL analyses, and that manual adjustment of these thresholds after visual inspection of the actigraphic data yielded more accurate results than automated scoring. Moreover, this study, which compared integrated data from both limbs as well as unilateral data, found that bilateral actigraphic data was more accurate than unilateral, and that data from the right leg was more strongly correlated with polysomnography than the left [14]. Notably, this study, along with the majority of other investigations that evaluated data from the left and right limbs, did not report which limb was dominant or more severely affected (e.g. if RLS symptoms were worse on one side).

Quantitative Synthesis—Five studies met criteria for quantitative meta-analysis [14, 16, 22, 24, 26]. It was anticipated *a priori* that both type of device and device placement would lead to significant variability among studies, which was confirmed by visual inspection of the data. As a result, three separate categories were examined separately: Actiwatch placed on the dorsum of the foot, Actiwatch placed on the ankle, and PAM-RL placed on the ankle (as no studies examined this device in an alternate placement). All analyses were initially performed using a PLMI cut-off of 5/hr since the majority of studies that met criteria for quantitative analysis utilized this threshold. The available studies all examined heterogeneous adult patient populations (e.g. mix of sleep-related movement disorders and sleep-related breathing disorders), and thus stratification by diagnosis and age was not performed.

There were three studies that reported bilateral data collected from the Actiwatch on the foot dorsum [14, 24, 26]. There was significant heterogeneity of the diagnostic odds ratio among these three studies (I^2=44.1%), and thus data was not pooled. Sensitivity ranged from 0.79 (95% CI 0.54–0.94) to 1.00 (95% CI 0.81–1.00), and specificity ranged from 0.60 (95% CI 0.15–0.95) to 0.83 (95%CI 0.59–0.96) for this device/placement (Figure 2a).

There were four studies that examined actigraph placement on the ankle that met criteria for quantitative analysis: two using the Actiwatch [16, 26] and two using the PAM-RL [14, 22]. There was no significant heterogeneity of the diagnostic odds ratio among studies using either the Actiwatch (I^2 = 0.0%) or PAM-RL (I^2= 0.0%) using PLMI threshold of 5/hr, and thus pooled analysis was conducted. The Actiwatch when placed at the ankle demonstrated a pooled sensitivity of 0.63 (95% CI 0.47–0.77) and specificity of 0.93 (95% CI 0.81–0.99) (Figure 2b). The PAM-RL demonstrated a pooled sensitivity of 0.95 (95% CI 0.85–0.99) and specificity of 0.56 (95% CI 0.21 to 0.86) (Figure 3a).

Because both studies that utilized the PAM-RL reported individual data for each subject, the sensitivity and specificity at a higher PLMI cut-offs (10/hr and 15/hr) was examined on an

exploratory basis. The diagnostic odds ratio at PLMI 10/hr demonstrated significant heterogeneity (I^2 = 32.1%), and thus pooling was not performed. However, high sensitivity for both studies (1.00 95% CI 0.87–1.00 and 0.59–1.00) was observed at this PLMI threshold, with more variable specificity that ranged from 0.33 (95% CI 0.01–0.91) to 0.75 (95% CI 0.48–0.93) (Figure 3b). The diagnostic odds ratio at PLMI 15/hr demonstrated no heterogeneity (I^2 = 0.0%) and thus data was combined, demonstrating a pooled sensitivity of 0.93 (95% CI 0.76 to 0.99) and specificity of 0.64 (95% CI 0.43–0.82), which was similar to values using PLMI cut-off of 5/hr (Figure 3c).

DISCUSSION

This systematic review and meta-analysis suggests leg actigraphy has promise as a means of assessing periodic limb movements of sleep compared to in-laboratory polysomnography. However, the relatively few existing studies have variable methodologies, complicating systematic comparison. Moreover, the limited number of studies and relatively small sample sizes requires that pooled sensitivity/specificity be interpreted with caution. There are also pragmatic concerns regarding the applicability of leg actigraphy that must be addressed before it can be considered a viable alternative diagnostic strategy to polysomnography in clinical practice.

This review suggests that the two most commonly studied actigraphs that have been utilized to quantify PLMS, the Actiwatch and the PAM-RL, may be useful in divergent clinical scenarios, due to differences in their sensitivity and specificity. In general, the sensitivity and specificity of the Actiwatch, when placed on the dorsum of the foot, provides more variable results than ankle placement, and thus the latter device placement appears to have greater clinical utility. When the Actiwatch has been used on the ankle, this method of quantifying PLMS has demonstrated high specificity, but lower sensitivity, at a PLMI cut-off of 5/hr. Conversely, the PAM-RL has high sensitivity with lower specificity at both a PLMI cut-off 5/hr and 15/hr. Thus, broadly speaking, the available literature suggests the Actiwatch placed on the ankle can be considered more reliable to rule-in PLMS when the result is positive, and the PAM-RL can be considered more reliable to rule-out PLMS when the result is negative.

Differences in the design of these devices may account for their discrepant sensitivities and specificities. The Actiwatch was originally designed as a wrist-worn actigraph that was adapted to use on the leg, and uses a uni-axial accelerometer to detect movements. The PAM-RL, however, was designed as a leg-worn accelerometer to detect PLMS, and utilizes a tri-axial sensor to detect limb movements. In addition, the PAM-RL has a position sensor that can detect when the patient is upright, and thus exclude leg movements that occur when standing (i.e. ambulating to the bathroom). However, neither device is capable of distinguishing sleep from wake, nor whether leg movements are due to respiratory events, and thus future research that integrates data from leg accelerometers with data collected via other portable monitoring devices that record such information, may be a fruitful avenue of investigation. Particularly promising would be leveraging these additional data to refine algorithms that distinguish periodic limb movements during wake and sleep, as well as

pseudo-PLMS (i.e. due to artifact or termination of an apnea/hypopnea) from true periodic limb movements.

A more pragmatic issue that may limit the clinical utility of these devices is the current difficulty in integrating data from each leg into one time series for analysis. The manufacturers of these devices and their related software have changed in the last several years. Currently, both the Actiwatch and PAM-RL are produced by a single company (Phillips Respironics) and with updates to the Actiwatch, the software that previously allowed for assessment of PLMS is no longer available [31]. In addition, the current software for use with the PAM-RL does not have the built-in capability to integrate the time series from both legs [31]. An ancillary software program, “Monitorlink” has been used in prior studies to circumvent this particular issue [14], however this software is considered “end-of-life” by the company that produced it, meaning there are no planned updates (final version dated February 2005) and support can not be provided for its use [32]. Thus, the use of integrated bilateral data to calculate PLMI is currently quite difficult and would require technical expertise that is likely beyond what the majority of sleep laboratories are willing to invest in terms of time and resources, particularly for a technology that is not considered part of routine clinical care. Thus, there appears to be a “chicken-and-egg” problem, in which there is limited clinical interest in the technology, leading to limited motivation on the part of commercial entities to advance development, and thus clinical interest remains low due to concerns about utility and practicality.

In the absence of a ready method for adapting data from both legs with available commercial leg accelerometers, the use of a single leg may be more pragmatic, though likely less accurate, than bilateral assessment [14]. Thus, further research is required to determine which leg (right vs. left, dominant vs. non-dominant, more affected vs. less affected, etc.) provides optimal sensitivity/specificity to quantify PLMS at various PLMI cut-points in clinical populations. Moreover, to allow for systematic assessment of diagnostic accuracy across studies, future manuscripts would provide sufficient data to construct two by two contingency tables for common PLMI cut-points, for both bilateral and unilateral data.

There are limitations of this systematic review that merit discussion. First, although sizeable efforts were made to include all relevant studies, it is possible that the systematic search strategy did not identify important research in this area. Additionally, this review focused on the diagnostic capacity of leg actigraphy to quantify PLMS, rather than the ability of these devices to accurately measure response to treatment over time. Thus the utility of leg actigraphy in this sphere of clinical management cannot be construed from this review, and further research in this area is warranted. Furthermore, the use of the PLMI derived from polysomnography as the reference standard has inherent limitations. Current scoring rules variably define criteria for scoring periodic limb movements of wake and thus calculating PLMI [8, 9, 30], which may be particularly problematic in disorders in which leg movements during wake are clinically relevant, such as RLS. Finally, the use of anterior tibialis EMG activity to determine PLMS during polysomnography may not detect pertinent nocturnal limb movements. Because the extensor digitorum brevis muscle has been shown to be more sensitive than the anterior tibialis in detection of limb movements via EMG [8, 9, 33], it is quite possible that sensitive actigraphs, such as the PAM-RL, may be able to more

accurately detect motion stemming from these alternate sources of lower extremity movement than polysomnography.

CONCLUSIONS

In summary, leg actigraphy is a promising means of quantifying periodic limb movements of sleep, however, the limited number of studies and variability of research methodologies currently obscures its clinical utility. Future research will hopefully advance this method of out-of-center testing for sleep-related limb movements, by identifying optimal standards of implementation, as well as specific clinical scenarios in which these devices may prove useful. In so doing, these efforts may provide the impetus to overcome the current pragmatic barriers that limit the widespread use of leg-worn actigraphy to quantify PLMS in clinical practice.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

AASM	American Academy of Sleep Medicine
DTS	diagnostic test study
EEG	electroencephalogram
EDS	excessive daytime sleepiness
EMG	electromyography
F	female
M	male
NR	not reported
OSA	obstructive sleep apnea
PLM	periodic limb movement
PLMS	periodic limb movements of sleep
PLMI	PLM index
PLMW	periodic limb movements of wake

PSG	polysomnography
RCT	randomized controlled trial
RLS	restless legs syndrome
SRBD	sleep-related breathing disorder
WASM	World Association of Sleep Medicine

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Practice Points

The diagnostic capabilities of leg-worn actigraphy to quantify periodic limb movements of sleep are likely affected by:

1. type and limb placement of the actigraph
2. criteria for scoring leg movements, including those occurring during wakefulness and respiratory events
3. methods used to integrate data from multiple limbs

Research Agenda

Further research is required to:

1. Determine the optimal diagnostic capabilities of unilateral leg actigraphy to quantify periodic limb movements of sleep
2. Develop methods for integration of data from both limbs in quantifying periodic limb movements of sleep
3. Combine data from other out-of-center diagnostic devices to improve the accuracy of leg-worn actigraphy
4. Determine specific scenarios in which leg actigraphy alters/improves clinical management of patients

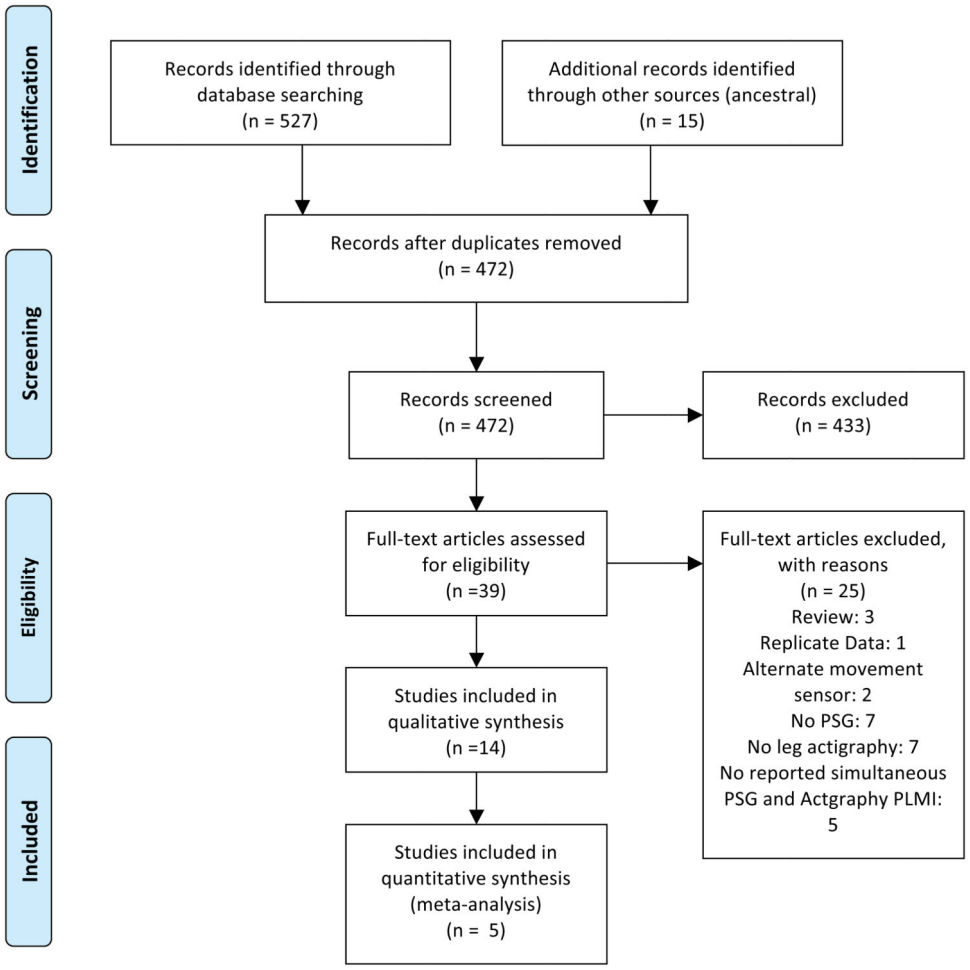

Figure 1.

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flow Diagram.

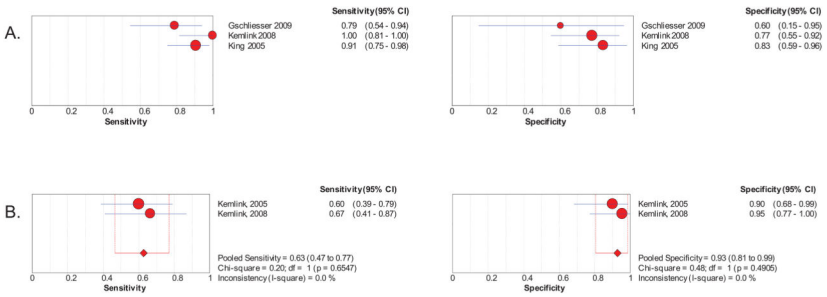

Figure 2.

Forest plots of sensitivity and specificity of Actiwatch to detect periodic limb movements at a PLMI threshold of 5/hr when placed on the A) dorsum of the feet and B) bilateral ankles. Data from the dorsum of the feet was not pooled due to heterogeneity of the diagnostic odds ratio (I^2 = 44.1%). Data from Kemlink et al., 2008 [26] is included in all plots because both foot dorsum and ankle placement were utilized within subjects on the same night.

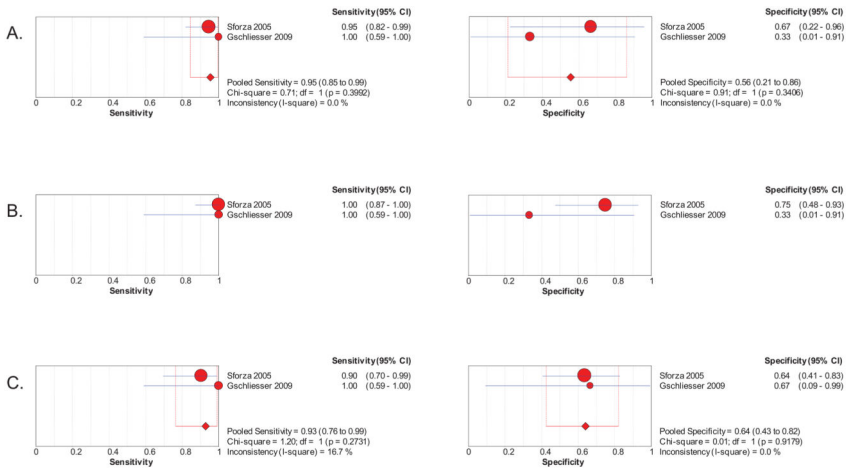

Figure 3.

Forest plots of sensitivity and specificity of PAM-RL to detect periodic limb movements at a PLMI threshold of A) 5/hr, B) 10/hr, and C) 15/hr. Data using PLMI cut-off of 10/hr was not pooled due to significant heterogeneity of the diagnostic odds ratio (I^2 = 32.1%) at this threshold.

Table 1

Table of Evidence.

Authors, reference number	Actigraph/Study Type	Settings	Placement	Participants	PLM index from PSG	PLM index from ACT	Findings*	PLMI cut-off	LOE	Notes
Kazenwadel et al. 1995[17]	Molvoport; DTS/RCT	Registration and digitization 10Hz	Dorsum of right foot	30 RLS patients (mean age 51.0, range 29–74; 18 M, 12 F) in a double-blind RCT	PLM/TIB	PLM/TIB	Sn/Sp NR r=0.87–0.91, p<0.001	NR	2b	TIB for PLMI calculation derived from PSG and ACT separately; Time spent out of bed excluded for both PSG and ACT PLMI calculations
Gorny et al. 1998[18]	PAM-RL; DTS	Unspecified	One leg (side unclear)	6 subjects (2 RLS, 2 PLMD, 2 controls; age/sex unspecified)	NR	NR	Sn/Sp NR Overall count agreement= 96.1%	NR	3b	Abstract; data from first 3 hours of sleep; agreement between PSG and PAM-RL based on PLM counts rather than PLMI
Gorny et al. 1998[19]	PAM-RL; DTS	Unspecified	Bilateral dorsum of foot	16 subjects (5 RLS, 5 PLMD, 5 controls; age/sex unspecified)	PLM during sleep	1) PLM during sleep and 2) during total sleep period (including sleep and wake times)	SP/SN NR r=0.879–0.998, p<0.0001	NR	2b	PSG scoring blinded to PAM-RL; total sleep period not defined; unspecified if during sleep equivalent to TST
Sforza et al. 1999[21]	“Swiss-type” activity monitor; DTS	Default	Dorsum of right foot	35 patients with sleep disorders undergoing PSG (54.8±1.6 years; 31 M and 4 F)	PLM/hour of sleep	PLM/hour of sleep	Sn/Sp NR r=0.78, p=0.001	NR	2b	Comparison of PSG and ACT performed on PLM rather than PLMI; Leg movements detected in wake and sleep, not explicit if TIB or TST utilized to calculate PLMI
Gorny et al. 2000[20]	PAM-RL; KickCounter; DTS	Unspecified	Unilateral leg (side unclear)	17 RLS patients, 7 insomnia patients, and 11 controls (unspecified age)	PLM/hour	PLM/hour	PAM-RL: r^2=0.92 Kick Counter: r^2=0.80	NR	2b	Abstract; methods for PLMI calculation not explicit
Sack et al. 2001[23]	Actiwatch; DTS	Unspecified	Bilateral dorsum of foot	30 patients undergoing PSG for SDB (22 M; 8 F)	PLMS per hour of sleep	PLMS per hour of sleep	Sn=0.88; Sp=0.86	5/hr Act and 10/Hr PSG	2b	Abstract; methods for PLMI (either PSG or ACT) calculation not explicit

Authors, reference number	Actigraph/Study Type	Settings	Placement	Participants	PLM index from PSG	PLM index from ACT	Findings*	PLMI cut-off	LOE	Notes
Kemlink et al. 2005[16]	Actigraph AW-64; DTS	Fundamental frequency 11 Hz, 2 sec epochs	Bilateral ankles	44 PSG nights in 42 adult patients (49.2±13.1 years; 32 M, 10 F) with RLS and/or SRDB	PLM/TST	PLM/TIB	Sn=0.60, Sp=0.90	5/hr	1b	Translated from Czech; 2 subjects with repeated recordings; PSG limb movements scored independent of respiratory events
King et al. 2005[24]	Actiwatch: DTS	Sampling rate 32Hz, 2 sec epochs	Dorsum of each foot	50 technically acceptable overnight hospital PSG (demographics unclear)	PLM/SPT	PLM/SPT	5/hr: Sn=0.906, Sp= 0.833 25/hr: Sn=1.00, Sp= 0.971 50/hr: Sn=1.00, Sp=0.978	≥5, ≥25, ≥50	1b	SPT defined by PSG for both ACT and PSG- derived PLM indices; PSG- derived limb movements scored independent of respiratory events
Montgomery- Downs, et al. 2005[25]	Actiwatch-64; DTS	Recorded in 2 sec epochs	Dorsum of each foot	99 children referred for PSG (4–12 years of age)	1) PLMS during sleep periods and 2) PLM (inclusive of arousals and wake)	1) PLM during sleep periods and 2) corrected PLM sans movements causing arousal	Sn/Sp NR Mean differences: Left-2.41 (7.31) Right-2.05 (5.74	NR	2b	Left and right legs compared separately; Examined relationships between two PLM indices derived from PSG and two from ACT; denominator for separate PLMI not universally specified
Sforza et al 2005[22]	PAM-RL; DTS	Sampling rate 40/sec	Bilateral ankles	43 consecutive adult patients (57.6±3.7 years old; 33 M and 10 F) referred for PSG for insomnia and/or EDS;	PLM/TIB	PLM/TIB	Sn=0.88, Sp=0.76 r=0.87, p<0.0001	10/hr	1b	Individual subject data available; Reported findings based on 50 studies
Oka et al. 2006[27]	PAM-RL; DTS	Unspecified	Unspecified	28 patients consulted in sleep disorders clinic (unknown age and sex)	PLM/TST	PLM/total recording time	Sn=0.89 Sp=0.81 r=0.92	15/hr	2b	Abstract; Methods do not specify if PLM is inclusive or exclusive of PLMW
Kemlink et al. 2008[26]	AW-64 Actiwatch; DTS	32 Hz resolution; 2 sec epochs	Bilateral ankles and dorsum of foot	40 consecutive nights in 37 adult patients with RLS and/or SRBDs (age 50.8±12.1 years; 29 M, 8 F)	PLM/TST	PLM/TIB	Ankle Sn=0.67, Sp=0.95 Toes Sn=1.00; Sp=0.77	5/hr	1b	3 patients monitored for 2 nights; PSG limb movements scored independent of respiratory events
Gschliesser et al. 2009[14]	PAM-RL; Actiwatch: DTS	Actiwatch: Sampled 32Hz.	Actiwatch- bilateral foot dorsa	24 consecutive patients (57.5±12 years; 18 M, 6 F);	PLM/TIB	PLM/TIB	Sn/Sp NR Actiwatch: r=0.835, p<0.001	NR	2b	Individual subject data in supplement

Authors, reference number	Actigraph/Study Type	Settings	Placement	Participants	PLM index from PSG	PLM index from ACT	Findings*	PLMI cut-off	LOE	Notes
		PAM-RL: Sampled10 Hz PAM-RL: Sampled10 Hz Default settings	PAM-RL- bilateral ankle	of these 10 (60.9±y12.0 years old; 7 M, 3 F,) underwent additional monitoring with PAM-RL			PAM-RL: r=0.939, p<0.001			
Rogers et al. 2012[28]	PAM-RL: DTS	Default Settings; sampling rate 40/sec	Bilateral ankle	20 pediatric patients with sickle cell anemia and RLS, suspected PLMS, or PLMI>5 on previous PSG	PLMS/TST	PLM/TIB (uncorrected); PLM/SPT (corrected)	5/hr: Sn=1.00, Sp=0.08 10/hr: Sn=1.00, Sp=0.54 15/hr: Sn=0.75; Sp=0.75	5/hr, 10/hr, 15/hr	2b	Data from 15 subjects and dominant ankle used for analysis

Abbreviations are as follows: DTS=diagnostic test study; RCT=randomized controlled trial; LOE=level of evidence; NR=not reported; RLS=restless legs syndrome; M=male; F=female; PSG=polysomnography; ACT=actigraphy; EDS=excessive daytime sleepiness; SRBD=sleep-related breathing disorder; PLM=periodic limb movements (here inclusive of wake and sleep); PLMS=periodic limb movements of sleep; PLMW=periodic limb movements of wake; TIB=time in bed; TST=total sleep time; SPT=sleep period time (start of first epoch of sleep/sleep onset to last epoch of sleep/morning waking).

*Sensitivity (Sn), Specificity (Sp), correlation coefficient (r), and overall count agreement refer to comparisons between periodic limb movements derived from polysomnography and leg-worn actigraphy.