Role of Wearable Accelerometer Devices in Delirium Studies: A Systematic Review

Anis Davoudi, MSc1,3; Todd M. Manini, PhD2; Azra Bihorac, MD3,4; Parisa Rashidi, PhD1,3

Objectives: We sought to determine the feasibility of using wearable accelerometer devices for determining delirium effects on patients’ physical activity patterns and detecting delirium and delirium subtype.

Data Sources: PubMed, Embase, and Web of Science.

Study Selection: Screening was performed using predefined search terms to identify original research studies using accelerometer devices for studying physical activity in relation to delirium.

Data Extraction: Key data were extracted from the selected articles.

Data Synthesis: Among the 14 studies identified, there were a total of 315 patients who wore accelerometer devices to record movements related to delirium. Eight studies (57.1%) used accelerometer devices to compare the activity of delirious and nondelirious patients. Delirious patients had lower activity levels, lower restlessness index, higher number of daytime immobility minutes, lower mean activity levels during the day, and higher mean activity levels at night. Delirious patients also had lower actual sleep time, lower sleep efficiency, fewer nighttime minutes resting, fewer minutes resting over 24 hours, and smaller change in activity from day to night. Six studies (42.9%) evaluated the feasibility of using accelerometer devices for detection of delirium and its subtype. Variables including number of postural changes during daytime, frequency of ultrashort, short, and continuous movements were significantly different among the nondelirium and the three delirium subtypes.

Conclusions: The results from the studies using accelerometer devices in studying delirium demonstrate that accelerometer devices can potentially detect the differences between delirious and nondelirious patients, detect delirium, and determine delirium subtype. We suggest the following directions as the next steps for future studies using accelerometer devices for predicting delirium: benchmark studies with longer data collection, larger and more diverse population size, incorporating related factors (e.g., medications), and evaluating delirium subtype and severity.

Key Words: actigraphy; circadian rhythm; delirium; intensive care units; wearable devices

Delirium—a serious acute neuropsychiatric syndrome characterized by cognitive decline—has a high prevalence of up to 80% in the ICUs (1, 2). Several risk factors prevalent among critical care patients have been identified for delirium. These risk factors include predisposing risk factors such as age and dementia, as well as precipitating risk factors such as previous history of delirium, emergency surgery, and mechanical ventilation (3–5). Delirium can negatively impact the health outcomes of patients (6–15) and has led to an estimated $38–$150 billion per year in healthcare expenditures in the United States (16). Treatment interventions that target delirium (17–20) require accurate and timely prediction and detection methods.

Delirium’s diagnostic criteria according to the Diagnostic and Statistical Manual of Mental Disorders, fifth edition include acute and fluctuating disturbance in attention and disturbance in cognition—for example, changes in perception, memory, reasoning, and visuospatial processing—which are not better explained by another neurocognitive disorder or the reduced level of arousal (20–22). Currently, delirium is detected through subjective assessments by the clinical staff, and the most frequently used assessment is the Confusion Assessment Method for the ICU (CAM-ICU) (23). Such detection methods have high sensitivity in research settings, but lower sensitivity in healthcare settings.
CAM-ICU can also be time-consuming, and since it is administered at most a few times per day, it cannot capture the fluctuating nature of delirium symptoms. Monitoring movement and sleep patterns offer a potential solution for predicting and detecting the onset of delirium. In fact, circadian disturbances (sleep-wake rhythm disruptions and motor activity alterations) are one of the core domains suggested for delirium detection (26).

Wearable accelerometers provide an approach to automatically capture patients’ activity cycle in a noninvasive manner (referred to as actigraphy) (27). Current accelerometer devices are small and lightweight (Fig. S1, Supplemental Digital Content 1, http://links.lww.com/CCX/A77) and offer unobtrusive data collection and long data collection periods (28). Wearable accelerometer devices are generally well-tolerated and have been used in public health research for studying the human activity patterns in various conditions and populations (29–31). They are also capable of characterizing circadian activity rhythms, which has been done in the different delirium subtypes, and between delirious and nondelirious patients (32–36). A previous review article published in 2011 had examined studies reporting 24-hour motor patterns in delirious patients (37), discussing the results of the studies based on the main research questions studies in each article: the correlation between delirium subtypes and activity patterns, and whether the Actiwatch is able to characterize the sleep-wake rhythm of delirious patients compared with that of nondelirious patients. An organized narrative of existing studies is needed to portray the current state of the literature for creating a frame of reference for building reliable delirium detection systems that use accelerometer devices.

**BACKGROUND**

**Activity and Circadian Rhythm**

Delirium can affect the circadian rhythm of patients’ physical activity. Accelerometer devices have been used to detect the changes in activity patterns of delirious patients (38). Researchers extract statistical features from data collected using accelerometer devices worn by patients, to recognize pattern modifications brought on by delirium (Tables 1 and 2). These statistical features portray both the average attributes of the patients’ activity (e.g., mean of activity counts during daytime) as well as the short-term (e.g., standard deviation of activity counts during daytime) and long-term variance in activity (e.g., intradaily variability [IV] of activity).

Delirium may also affect the sleep quality of the patients. The relationship between sleep deprivation and delirium has been studied for many years (39, 40). However, methodological issues related to the delirium assessment (41, 42) and sleep measurement in ICU (43, 44) make it difficult to establish the relationship.

| Variable | Description |
|----------|-------------|
| Restlessness index | Addition of percentage of time moving and percentage of immobility phases of 1 min |
| Number of minutes immobile | Total number of minutes where a score of zero was recorded |
| Mean activity per minute | Average activity score in those 1-min epochs where scores of > 0 were recorded |
| Intradaily variability | Representing the frequency and extent of transitions between rest and activity |
| Lowest mean activity during any stretch of 5 continuous hours (L5) | Mean activity of the 5 hr with the lowest activity within the 24 hr |
| Highest mean activity during any stretch of 10 continuous hours (M10) | Mean activity of the 10 hr with the highest activity within the first 24 hr |
| Relative amplitude | (M10–L5)/(M10 + L5) |

*Can be calculated per nighttime, for example, (23:00 to 06:00) and daytime, for example, (06:00 to 23:00)*

| Variable | Description |
|----------|-------------|
| Total sleep time | Actual time spent asleep |
| Sleep efficiency | Percentage of time between sleep onset and final awakening, which was spent asleep |
| Sleep latency | Time from lights out until sleep onset |
| Wake after sleep onset | Amount of time awake during the night after sleep onset |
| Intermittent awakenings | Total awakening time after sleep onset |
between delirium and sleep deprivation. Sleep disturbances such as sleep fragmentation and spread of sleep during the 24-hour period have often been observed in delirious patients (34, 36, 45, 46). In the ICU, sleep periods can be scattered throughout the day and fragmented at night (40, 43, 47); almost 50% of the ICU patients’ sleep happens in short bouts during the day, with little to no rapid eye movement sleep and increased light sleep (39). There is not yet a perfect approach to measure sleep quality parameters objectively and continuously. Current approaches for sleep measurement include polysomnography, electroencephalography, and sleep diaries or sleep reports. These methods each have shortcomings; polysomnography and electroencephalography are cumbersome to employ, expensive and time-consuming to interpret; their data may also be confounded by medical conditions such as renal failure and sedative and analgesic medications, which are common in the ICU population (48). Sleep diaries and self-reports from the patients and/or nurses are also limited; these methods suffer from recall bias or failure in assessing daytime sleep characteristics, and the fact that diaries and self-reports are limited to conscious and stable patients, practically excluding many delirious patients (48, 49). If delirium and sleep deprivation are found to be indeed related, tracking sleep quality parameters should be incorporated in systems proposed for delirium detection and tracking efficacy of interventions.

Comparatively, accelerometer devices are easy to use, generally well-tolerated, and can be worn for long periods of time (50). However, actigraphy cannot be used for detecting different stages of sleep. Furthermore, although actigraphy has been used for sleep measurement in postsurgery patients (51), it has not been validated for ICU populations, and cannot yet be relied on for sleep characterization among them, partially because ICU patients may be restricted by neuromuscular weakness, sedatives, or restraints (49). Evaluation of sleep in ICU patients using accelerometer devices might lead to overestimation of total sleep time and sleep efficiency and has reduced validity for detection of sleep onset and wake after sleep onset (WASO) detection (51–54). Physical restraints—prevalent in the critical care settings for the purpose of preventing patients from disrupting medical devices, while a risk factor of delirium—significantly affects the physical activity patterns of the patients as it limits the patients’ movements, rendering the use of accelerometers unsuitable (55, 56).

However, wearable accelerometers can still be used for detecting the “rest” and “active” periods in patients’ physical activity. Rest-activity cycle may be used as a proxy for the sleep-wake cycle for populations where continuous sleep measurement is challenging. Recovery in 24-hour rest-activity periodicity can indicate improvement in the patient’s status, compared with lack of the recovery of the rest-activity periodicity in delirious patients, reflected by significant differences in rest-activity pattern variables between delirious patients and nondelirious patients (57).

**Delirium Detection**

Alterations in motor activity are among the main established symptoms of delirium (26). While other symptoms of delirium such as fluctuations in cognitive abilities and emotional state of the patients are not easily quantified using automated methods, physical activity levels of patients are more amenable to assessment using physiologic sensors such as accelerometers. Actigraphy approaches can potentially be used for quantifying the distortions and alterations in patients’ physical activity. Physical activity patterns measured using accelerometers can be used for investigating the differences in the psychomotor profiles of delirious versus nondelirious patients, and among the patients with different delirium subtypes to determine the delirium subtype.

Honma et al (58) was the first study to use data from wearable accelerometers to study the differences in the motor activity patterns related to delirium. Since then, delirium subtypes have been defined and their psychomotor criteria have been determined in various studies (32–36). Delirium can be classified into three subtypes based on psychomotor behavior: hyperactive, hypoactive, and mixed (59, 60). Hyperactive delirium is often characterized by hallucinations, delusions, agitation, and disorientation. Hypoactive delirium is characterized by confusion and sedation, and mixed delirium has alternating features of hyperactive and hypoactive delirium (16, 61, 62). It has been suggested that each delirium subtype may have its own unique pathophysiology and may respond differently to treatments, which indicates the benefits of subtyping a patient’s delirium to decide their specific best course of action.

**MATERIALS AND METHODS**

This review study focuses on two interrelated main themes: 1) use of wearable accelerometers in studying the rest-activity cycle in delirium and 2) use of wearable accelerometer devices in delirium detection. We searched the PubMed, Embase, and Web of Science databases using the following keywords combinations: actigraph* AND delir*, accelerometer AND delir* AND actigraph*, delir* AND actigraph* AND activity, and actiometry AND delir* until January 1, 2018. We searched for original research studies written in English and published in peer-reviewed conferences and journals containing adult delirium patients (> 18 yr old). We selected only those that had used accelerometer devices studying delirium. Search strategies are available in Table S1 (Supplemental Digital Content 2, http://links.lww.com/CCX/A78), Table S2 (Supplemental Digital Content 3, http://links.lww.com/CCX/A79), and Table S3 (Supplemental Digital Content 4, http://links.lww.com/CCX/A80).

We assessed the full texts of all articles after removing the duplicate titles. We used data abstraction forms to collect the relevant study information. We then characterized the studies on the following criteria: year of publication; number of participants and cohort characteristics; delirium detection tool; delirium prevalence in the cohort; device used; device placement on the body; duration of data collection; variables studied; and results. Risk of bias in included studies was examined using National Heart, Lung, and Blood Institute Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (63). The results are reported according to the Preferred Reporting Items for Systematic Reviews and Meta- Analyses guidelines (http://www.prisma-statement.org) (64).
RESULTS

Our search resulted in 51 articles after removing articles repeated in different search keyword pairs. The final number of articles included are 14 (Fig. S2, Supplemental Digital Content 5, http://links.lww.com/CCX/A81). Articles with the following criteria were excluded review articles (n = 2), case studies (n = 2), study protocols (n = 2), non-English (n = 2), pediatric patients (n = 2), did not include delirium as an outcome (n = 19), comment- tary articles (n = 1), and posters (n = 7). Combined, the studies enrolled 315 patients, with a median of 28 patients (interquar- tile range, 11.75–57.25; range, 8–101). The duration of accelerometer recordings ranged from 24 hours to more than 10 days. Among all the 14 studies, six (42.9%) used CAM or CAM-ICU, nine (64.3%) used Delirium Rating Scale-Revised-98 (DRS-R-98), one (7.1%) used Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revision, one used 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10) (7.1%), and one (7.1%) used Revised Hasegawa Dementia Rating Scale (65) to detect delirium. In eight studies (57.1%), the patients wore the accelerometer on their wrist, and in six studies patients (42.9%) wore the device on their mid-thigh.

Actigraphy and Physical Activity Pattern

The studies that used wearable accelerometers to assess the effect of delirium on physical activity patterns only included elderly patients (65 yr old or older). Only one study had included the delirium subtype in their evaluations; thus, the results should be considered with caution since different delirium subtypes have different motor activity characteristics. Although the variables studied were not all common among the six studies, four studies had reported that delirious patients had significantly lower average activity over 24 hours and during the daytime, but higher average activity during nighttime. These studies reported that delirious patients generally have significantly reduced restlessness, the mean activity of the 5 hours with the least activity (L5), and a larger number of immobility minutes (Table 3).

Delirious patients had higher IV, which quantifies rhythm fragmentation. High IV values can be indicative of daytime rest and/or nighttime activity, making IV an indicator of sleep/wake cycle disturbances (66). Furthermore, in the only study that had incorporated delirium severity in its analysis, the severity of delirium was positively correlated with mean activity count at night, and negatively correlated with number of nighttime minutes at rest, number of minutes at rest over the 24-hour period, and amplitude of change in mean activity from day to night, advocating the disruptive effect of delirium on nighttime rest and circadian rhythm of rest-activity cycle (57).

Out of the three studies that used accelerometers to study the effect of delirium on sleep quality parameters, two studies were performed on elderly patients (65 yr old and older), and the remaining study was restricted to patients 40 years old or older. Even though actigraphy methods are not reliable for sleep detection in the ICU, sleep reported using actigraphy approaches have shown significant differences between sleep quality parameters of preoperative sleep among patients with and without postoperative delirium (67) (Table 4); showing that delirious patients had significantly lower sleep efficiency (captured as lower sleep efficiency or higher WASO %). Half of the studies included in the studies measuring physical activity in delirious and nondelirious populations had higher risk of bias. Two studies were using subsets of the same patient populations, with different statistical analyses (Table S4, Supplemental Digital Content 6, http://links.lww.com/CCX/A82).

Actigraphy and Delirium Detection

Researchers have used wearable accelerometers to evaluate the feasibility of delirium detection and delirium subtype determination using accelerometer data. All the six studies using accelerometer data for delirium detection or delirium subtype determination were done on palliative/hospice care patients, with data collected for 24 hours; and the participants wore an activPal (PAL Technologies, Glasgow, United Kingdom) on mid-thigh (Table 5). Their results show that delirious and nondelirious patients are different in terms of percentage of total time spent in dynamic activity, number of postural changes occurring over 24 hours, daytime versus nighttime, number of movements of differing durations, and total summated times per activity of sitting/lying, standing, and stepping. These differences, along with continuous wavelet transforms of the collected accelerometry data were used to train classifiers to detect delirium subtypes (68–73), and the best model had an accuracy of 92.3% in classifying delirium subtypes. Two out of six studies using physical activity to detect delirium had low quality in terms of bias, whereas four other studies had fair quality in terms of bias. All these six studies used the same patient population with different statistical analyses (Table S4, Supplemental Digital Content 6, http://links.lww.com/CCX/A82).

DISCUSSION

In this systematic review, we focused on studies that use accelerometer data to investigate delirium. We found two main themes: 1) studies using accelerometer data for studying patients’ motor activity and rest-activity cycle and 2) studies using accelerometer data for delirium detection and delirium subtype determination. Although the number of studies in this review article is small, we were able to identify both the contributions of and the limitations of each study, regarding both main themes.

Previous studies were unable to showcase the ability of wearable accelerometers to detect sleep in ICU patients; however, several studies have suggested similarities between ICU patients’ sleep/wake cycle and rest/activity cycle; and wearable accelerometers can be used to characterize the rest/activity periods of these patients. Actigraphy methods may provide an objective measure to gauge the effectiveness of delirium treatment interventions in normalizing diurnal rhythms and physical activity patterns. Another relevant factor is patients’ sleep and functional status at home; which, along with baseline sleep quality parameters at hospital are currently not collected. With the increase in smartwatches and other wearable fitness-tracking devices that collect accelerometer data, patients’ activity information from prior to their hospital admission can be collected and used in delirium prediction models, particularly for elderly adults and patients suffering from
| References | No. of Participants | Delirium Detection Tool | Delirium Prevalence in Population | Duration of Data Collection/Analysis | Variables Studied | Results | Device Used |
|------------|---------------------|-------------------------|----------------------------------|-------------------------------------|-------------------|---------|-------------|
| Osse et al (79) | 79 patients (65 yr old or older) following cardiac surgery | CAM-ICU, DRS-R-98 | Sustained delirium: 17 Short-delirium: 6 Nondelirium: 46 | 5 postoperative days | Mean activity per minute Immobility minutes Restlessness index Activity amplitude | Patients with sustained delirium had Lower activity values Lower restlessness index Higher number of daytime immobility minutes | Actiwatch actigraph (Cambridge Neurotechnology, Cambridge, United Kingdom) |
| Osse et al (38) | 70 patients (65 yr old or older) following elective cardiac surgery | CAM-ICU, Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revision | Delirious: 38 Nondelirious: 32 | Collected for 6 d, only used first day for analysis | Immobility Mean activity Restlessness L5 during the first 24 hr M10 during the first 24 hr | Delirious patients had significantly Lower mean activity level during the first postoperative night among delirious patients Reduced restlessness during the first postoperative day among delirious patients Lower M5 during the first 24 hr Higher number of immobile minutes Lower mean activity level | Actiwatch actigraph |
| Van Uitert et al (37) | 8 patients (65 yr old or older) with a hip fracture in need of surgical repair | CAM | Delirious days: 29 Nondelirious days: 24 | Worn for 5–7 d Number of days used for analysis not reported | Actual sleep time Sleep efficiency Sleep latency Duration of sleep bouts Duration of wake bouts IV L5 M10 RA | Delirious patients had significantly Lower actual sleep time Lower sleep efficiency Longer duration of sleep bouts Higher sleep latency Higher IV Lower RA | Actiwatch actigraph |
| Honma et al (58) | 8 patients (74–96 yr old) | Revised Hasegawa Dementia Rating Scale | 8 demented patients with delirium | More than 10 d Observational study: data not summarized | Divided patients into four groups based on their average daily and nocturnal activity | A wrist actigraph (Ambulatory Monitoring, Ardsley, NY) |
| Eeles et al (80) | 16 patients (76–95 yr) admitted to the hospital with delirium | DRS-R-98 | Delirious: 16 Hyper: 7 Hypo: 2 Mixed: 7 | Does not explicitly say the data collection length, but says data are analyzed at day 1, 2, 3, 5, and 7 | Average activity per minute Day-to-night ratio of activity | No relationship between clinical construct of delirium subtype and actigraphy in relation to average activity per minute or day-to-night ratio | Does not state |
| Jacobson et al (57) | 13 postoperative patients (67–91 yr) | DRS-R-98, CAM | Delirious: 6 Nondelirious: 7 | 24–72 hr | Minutes active daytime Minutes resting nighttime Total 24-hr rest (min) MAC daytime MAC nighttime 24-hr amplitude (MAC<sub>day</sub>–MAC<sub>night</sub>) | Delirious patients had Fewer nighttime minutes resting Fewer minutes resting over 24 hr Larger mean activity at night Smaller change in activity from day to night | Octagonal Basic Motionlogger (Ambulatory Monitoring, Ardsley, NY) |

CAM-ICU = Confusion Assessment Method for the ICU, DRS-R-98 = Delirium Rating Scale-Revised-98, IV = intradaily variability, MAC = mean activity count, RA = relative amplitude.

*In all studies in Table 3, devices were worn on the nondominant wrist, except for (80) which only states that the device was worn on the wrist.

*Mean activity of the 5 hr with the lowest activity within the first 24 hr.

*Mean activity of the 10 hr with the highest activity within the first 24 hr.
| References          | No. of Participants | Delirium Detection Tool | Delirium Prevalence in Population | Duration of Data Collection/Analysis | Variables Studied | Results | Device Used                     |
|---------------------|---------------------|-------------------------|-----------------------------------|-------------------------------------|-------------------|---------|----------------------------------|
| Van Uitert et al (37)<sup>a</sup> | 8 patients (65 yr old or older) with a hip fracture in need of surgical repair | CAM                      | Delirious days: 29 Nondelirious days: 24 | Worn for 5–7 d Number of days used for analysis not reported | Actual sleep time Sleep efficiency Sleep latency Duration of sleep bouts Duration of wake bouts IV L5<sup>b</sup> M10<sup>c</sup> RA | Delirious patients had significantly Lower actual sleep time Lower sleep efficiency Longer duration of sleep bouts Higher sleep latency Higher IV Lower RA | Actiwatch (Cambridge Neurotechnology, Cambridge, United Kingdom) |
| Leung et al (81)<sup>a</sup> | 50 patients (40 yr old or older) scheduled for major noncardiac surgery | CAM                      | Delirious: 7 Nondelirious: 43 | 3 preoperative days 3 postoperative days | Time in bed (min) Sleep onset latency (min) Sleep time (min) Wake time (min) Sleep efficiency (%) Sleep ratio Wake onset to offset (min) WASO (%) Number of awakenings | Delirious patients had significantly higher Wake time (min) Wake onset to offset (min) WASO (%) Number of awakenings | Mini Motionlogger Actigraph (Ambulatory, Ardsley, NY) |
| Todd et al (67)<sup>a</sup> | 101 patients (65 yr old or older) undergoing elective surgery | CAM International Statistical Classification of Diseases and Related Health Problems, 10th revision (ICD-10) | Delirious: 27 Nondelirious: 74 | 5 d | Preoperative sleep disruption in hospital, WASO (%) Postoperative sleep disruption in hospital, WASO (%) Difference between pre- and postoperative sleep disruption, WASO (%) | Patients who developed postoperative delirium had Significantly higher preoperative sleep disruption | Actiwatch |

CAM = Confusion Assessment Method, IV = intradaily variability, RA = relative amplitude, WASO = wake after sleep onset.

<sup>a</sup>In all studies in Table 4, the participants wore the wearable accelerometers on their nondominant wrist, except for (81) where the participants wore the device on their wrist.

<sup>b</sup> Least active 5-hr period in the average 24-hr pattern.

<sup>c</sup> Most active 10-hr period in the average 24-hr pattern.
medical issues before hospital admission. These objective activity data may give a more reliable baseline for patients' physical activity before ICU admission.

Previous works with actigraphy for delirium detection show its potential in differentiating between delirious and nondelirious patients, and among patients with different subtypes of delirium.

**TABLE 5. Characteristics of Studies That Have Used Actigraphy Devices to Explore Differences Among Delirious (Different Subtypes) and Nondelirious Patients' Physical Activity Parameters**

| References         | No. of Participants | Delirium Detection Tool | Delirium Prevalence | Variables Studied                          | Results                                                                 |
|--------------------|---------------------|-------------------------|---------------------|--------------------------------------------|------------------------------------------------------------------------|
| Godfrey et al (71)* | 40, hospice, palliative care unit patients | DRS-R-98 MDAS | Delirious: 25 Hyper: 6 Hypo: 10 Mixed: 9 Nondelirious: 9 | CWT with various mother Wavelets | Tree classifier had 96% overall accuracy for determining the delirium subtypes Nondelirious patients were generally classified as mixed delirious |
| Godfrey et al (73)* | 3, hospice, palliative care unit patients | DRS-R-98 MDAS | Delirious: 3 Hyper: 1 Hypo: 1 Mixed: 1 | CWT with various mother Wavelets | CWTs were compared for the feasibility of differentiating between three patients, one from each delirium subtype |
| Godfrey et al (70)* | 40, hospice, palliative care unit patients | DRS-R-98 | Delirious: 25 Hyper: 6 Hypo: 10 Mixed: 9 Nondelirious: 9 | Discrete wavelet transform applied for lying, sitting, and walking activities | Individual comparisons between the classification results and the outcomes of DRS-R98, MDAS, and Delirium Motoric Checklist resulted in 70%, 40%, and 40% accuracies, respectively |
| Godfrey et al (68)* | 40, hospice, palliative care unit patients | DRS-R-98 | Delirious: 25 Hyper: 6 Hypo: 10 Mixed: 9 Nondelirious: 9 | Time spent in dynamic activity and postural changes during the day (10 AM to 6 PM) Time spent in dynamic activity and postural changes during the night (10 PM to 6 AM) Time spent in dynamic activity and postural changes during the sundowning period (6 PM to 10 PM) Postural changes over 24 hr Postural changes in daytime (10 AM to 6 PM) Postural changes in nighttime (10 PM to 6 AM) Postural changes sundowning (6–10 PM) Number of ultrashort movements (< 20 s duration) Number of short movements (20–60 s duration) Number of long movements (> 60 s duration) | Discriminating features Number of postural changes during daytime Frequency of ultrashort, short, and continuous movements Nondelirious patients were significantly different from Hypoactive delirious patients in a broad range of variables Mixed delirious patients in relation to overall postural transitions and frequency of ultrashort and short movements Not significantly different from hyperactive delirious patients Nondelirious patients and hyperactive delirious patients had similar motor activity profiles |

CWT = continuous wavelet transform, DRS-R-98 = Delirium Rating Scale-Revised-98, MDAS = Memorial Delirium Assessment Scale.  
*AAll the studies in Table 5 were performed on the same patient population (hospice, palliative care unit patients), and data were collected for 24 hr, with the patients wearing the activPal (PAL Technologies, Glasgow, United Kingdom) accelerometer device on their mid-thigh.  
*Data were collected for 40 patients, data from 34 patients were included in the analysis.
(Table 5). However, this has not been examined in general ICU population—where delirium is most present—to evaluate its performance for the following tasks: 1) delirium detection, 2) delirium subtype determination, and 3) to track patients’ recovery over their stay in ICU in terms of their sleep quality and improvement in their circadian rhythm disturbance. The reviewed studies focusing on delirium detection had collected data for only 24 hours, and only on the thigh, which does not realize the full potential of actigraphy methods. For example, other studies have seen significant differences between actigraphy features collected for delirious and nondelirious groups collected on the wrist (Table 3). These features can potentially be used for delirium detection.

Wearable accelerometers have been widely accepted to measure physical activity and are generally well-tolerated (74). This review identifies the following limitations in the literature: 1) small sample size, 2) short duration of data collection, 3) not investigating the effect of sedatives or other drugs on patients’ activity levels, 4) not considering the severity of delirium, 5) not characterizing delirium subtype, 6) only doing the study in certain patient populations and age ranges, 7) potential influence of device body placement, and 8) a limited number of delirium assessments, possibly leading to underestimation of delirium. Also, the heterogeneous pool of delirium assessment tools used for detection of delirium and the variables used prevents comparison and generalization of the results. The factors contribute to low quality of the studies in terms of risk of bias, in turn increasing the bias of the results reported in this review.

Future efforts should examine selecting the best position (e.g., hip, wrist, arm, ankle, or combinations) for mounting the accelerometer devices and validating and calibrating such positions. The use of accelerometer devices for studying delirium in more diverse and larger cohorts will provide more generalizable results. Furthermore, studies should aim to collect data over longer periods of time, which would allow for evaluating the intra-patient and inter-patient correlation of the accelerometer data with delirium severity. More studies are needed to evaluate the effect of sedative and psychotropic/antipsychotropic medications and their wear off time on the patients’ activity. In addition, future studies should examine how actigraphy can be used for detection of the alterations in the rest/activity cycle of the patients and detecting the patients’ recovery through tracking the recovery of the circadian activity rhythms of the patients. Currently, the only intervention to reduce the duration of delirium in the critical care settings is the early and progressive mobility as part of the ABCDEF bundle—a multicomponent, evidence-based guideline for optimizing recovery in the ICU. Early mobilization of the patients, as well as sleep hygiene, are also strongly recommended in the Clinical Practice Guidelines for the Management of Pain, Agitation, and Delirium in Adult Patients in the ICU (75). Measuring patients’ physical activity using wearable accelerometer devices will facilitate such efforts for quantifying patients’ mobility and monitoring its recovery during their stay in the ICU (76).

Future studies can also benefit from recruiting patients starting at their admission to ICU and recording patients’ activity levels during their ICU stay. Such an approach would allow researchers to detect delirium any time it occurs in the ICU, as well as to capture pertinent accelerometer data before and after delirium events. Data captured outside of delirium events may allow us to identify changes that lead to delirium, as well as how recovery from delirium is manifested in activity patterns. This information can both increase the timeliness of delirium detection and increase our understanding of how delirium affects patients’ activity in a more quantifiable manner.

CONCLUSIONS

Data from delirium investigations using wearable accelerometers indicate that these devices can detect the differences in the physical activity patterns of delirious and nondelirious patients. The detected quantified differences can both increase our knowledge in the effect of delirium on patients’ psychomotor characteristics and be used for detection of delirium and determining the delirium subtypes. The value of using wearable accelerometer devices for monitoring patients for delirium detection lies in their capability for nonintrusive, continuous, long-term data collection. Future works need to generate more data to advance our understanding of psychomotor characteristics of different delirium subtypes in various patient populations, so that we may develop reliable delirium detection algorithms incorporating data from wearable accelerometer devices.

REFERENCES

1. Pandharipande P, Cotton BA, Shintani A, et al: Prevalence and risk factors for development of delirium in surgical and trauma intensive care unit patients. *J Trauma* 2008; 65:34–41
2. Girard TD, Pandharipande PP, Ely EW: Delirium in the intensive care unit. *Crit Care* 2008; 12(Suppl 3):S3
3. Zaal IJ, Devlin JW, Peelen LM, et al: A systematic review of risk factors for delirium in the ICU. *Crit Care Med* 2015; 43:40–47
4. Inouye SK, Charpentier PA: Precipitating factors for delirium in hospitalized elderly persons. Predictive model and interrelationship with baseline vulnerability. *JAMA* 1996; 275:852–857
5. Mattar I, Chan MF, Childs C: Risk factors for acute delirium in critically ill adult patients: A systematic review. *IRCS Medical Science* 2013; 2013:10
6. Bickel H, Gradinger R, Kochs E, et al: High risk of cognitive and functional decline after postoperative delirium. A three-year prospective study. *Dement Geriatr Cogn Disord* 2008; 26:26–31
7. Pisani MA, Friesen RS, Gehlbach BK, et al: Sleep in the intensive care unit. *Am J Respir Crit Care Med* 2015; 191:731–738
8. Girard TD, Jackson JC, Pandharipande PP, et al: Delirium as a predictor of long-term cognitive impairment in survivors of critical illness. *Crit Care Med* 2010; 38:1513–1520
9. Ely EW, Gautam S, Margolin R, et al: The impact of delirium in the intensive care unit on hospital length of stay. *Intensive Care Med* 2001; 27:1892–1900
10. Ely EW, Shintani A, Truman B, et al: Delirium as a predictor of mortality in mechanically ventilated patients in the intensive care unit. *JAMA* 2004; 291:1753–1762
11. Thomas JW, Shintani A, Peterson JE, et al: Intensive care unit delirium is an independent predictor of longer hospital stay: A prospective analysis of 261 non-ventilated patients. *Crit Care* 2005; 9:R375–R381
12. McCusker J, Cole M, Dendukuri N, et al: Delirium in older medical inpatients and subsequent cognitive and functional status: A prospective study. *CMAJ* 2001; 165:575–583
13. McCusker J, Cole M, Abrahamowicz M, et al: Delirium predicts 12-month mortality. *Arch Intern Med* 2002; 162:457–463
14. Givens JL, Sanft TB, Marcantonio ER: Functional recovery after hip fracture: The combined effects of depressive symptoms, cognitive impairment, and delirium. *J Am Geriatr Soc* 2008; 56:1075–1079.

15. Rudolph JL, Inouye SK, Jones RN, et al: Delirium: An independent predictor of functional decline after cardiac surgery. *J Am Geriatr Soc* 2010; 58:643–649.

16. Leslie DL, Marcantonio ER, Zhang Y, et al: One-year health care costs associated with delirium in the elderly population. *Arch Intern Med* 2008; 168:27–32.

17. Schrader SL, Wellick KE, Demaerschalk BM, et al: Adjunctive haloperidol prophylaxis reduces postoperative delirium severity and duration in at-risk elderly patients. *Neurologist* 2008; 14:134–137.

18. Brummel NE, Girard TD: Preventing delirium in the intensive care unit. *Curr Crit Care* 2013; 29:51–65.

19. Smith CD, Grami P: Feasibility and effectiveness of a delirium prevention bundle in critically ill patients. *Am J Crit Care* 2016; 26:19–27.

20. Fong TG, Tulebaev SR, Inouye SK: Delirium in elderly adults: Diagnosis, prevention and treatment. *Nat Rev Neurol* 2009; 5:210–220.

21. Safavynia SA, Arora S, Pryor KO, et al: An update on postoperative delirium: Clinical features, neuropathogenesis, and perioperative management. *Curr Anesthesiol Rep* 2018; 8:252–262.

22. American Psychiatric Association: Diagnostic and Statistical Manual of Mental Disorders (DSM-5®). Arlington, VA, American Psychiatric Association, 2013.

23. Ely EW, Margolin R, Francis J, et al: Evaluation of delirium in critically ill patients: Validation of the confusion assessment method for the intensive care unit (CAM-ICU). *Crit Care Med* 2001; 29:1370–1379.

24. van Eijk MM, van den Boogaard M, van Marum RJ, et al: Routine use of the bedside diagnosis of ICU delirium: Specificity is high, let's optimize sensitivity. *Am J Respir Crit Care Med* 2011; 184:340–344.

25. Eijk MMv, Sloop AJ, Boogaard Mvd: The bedside diagnosis of ICU delirium: Specificity is high, let's optimize sensitivity. *Am J Respir Crit Care Med* 2012; 185:108.

26. Franco JG, Trzepacz PT, Meagher DJ, et al: Three core domains of delirium validated using exploratory and confirmatory factor analyses. *Psychosomatics* 2013; 54:227–238.

27. Tryon WW: Methods of measuring human activity. *J Behav Anal Health, Sports, Fitness Med* 2008; 1:58–71.

28. Martin JL, Hakim AD: Wrist actigraphy. *Chest* 2011; 139:1514–1527.

29. Davoudi A, Corbett DB, Ozrazgat-Baslanti T, et al: Activity and circadian rhythm of sepsis patients in the intensive care unit. *IEEE EMBS Int Conf Biomed Health Inform* 2018; 2018:17–20.

30. Li YN, Shapiro B, Kim JC, et al: Association between quality of life and anxiety, depression, physical activity and physical performance in maintenance hemodialysis patients. *Chronic Dis Trans Med* 2016; 2:110–119.

31. De Crescenzo F, Economou A, Sharpley AL, et al: Actigraphic features of bipolar disorder: A systematic review and meta-analysis. *Sleep Med Rev* 2017; 33:58–69.

32. Liptzin B, Levkoff SE: An empirical study of delirium subtypes. *Br J Psychiatry* 1992; 161:843–845.

33. Meagher DJ, O’Hanlon D, O’Mahony E, et al: Relationship between symptoms and motoric subtype of delirium. *J Neuropsychiatry Clin Neurosci* 2000; 12:51–56.

34. Meagher DJ, Moran M, Raju B, et al: Motor symptoms in 100 patients with delirium versus control subjects: Comparison of subtyping methods. *Psychosomatics* 2008; 49:300–308.

35. Meagher D: Motor subtypes of delirium: Past, present and future. *Int Rev Psychiatry* 2009; 21:59–73.

36. Meagher DJ, Leonard M, Donnelly S, et al: A longitudinal study of motor subtypes in delirium: Frequency and stability during episodes. *J Psychosom Res* 2012; 72:236–241.

37. van Uitert M, de Jonghe A, de Gijsel S, et al: Rest-activity patterns in patients with delirium. *Rejuvenation Res* 2011; 14:483–490.

38. Osse RJ, Tulen JH, Hengeveld MW, et al: Screening methods for delirium: Early diagnosis by means of objective quantification of motor activity patterns using wrist-actigraphy. *Interact Cardiovasc Thorac Surg* 2009; 8:344–348; discussion 348.

39. Watson PL, Ceriana P, Fanfulla F: Delirium: Is sleep important? *Best Pract Res Clin Anaesthesiol* 2012; 26:355–366.

40. Weinhouse GL, Schwaib RJ, Watson PL, et al: Bench-to-bedside review: Delirium in ICU patients - importance of sleep deprivation. *Crit Care* 2009; 13:234.

41. Lawlor PG, Bush SH: Delirium diagnosis, screening and management. *Curr Opin Support Palliat Care* 2014; 8:286–295.

42. Smith HA, Han JH, Ely EW: Meeting the challenges of delirium assessment across the aging spectrum. *Crit Care Med* 2016; 44:1775–1777.

43. Delaney LJ, Van Haren F, Currie M, et al: Sleep monitoring techniques within intensive care. *Int J Nurs Clin Pract* 2015; 2:1JNPC-114.

44. Bourne RS, Minelli C, Mills GH, et al: Clinical review: Sleep measurement in critical care patients: Research and clinical implications. *Crit Care* 2007; 11:226.

45. Fitzgerald JM, Adams D, Trzepacz PT, et al: Delirium: A disturbance of circadian integrity? *Med Hypotheses* 2013; 81:568–576.

46. Meagher DJ, Moran M, Raju B, et al: Phenomenology of delirium. Assessment of 100 adult cases using standardised measures. *Br J Psychiatry* 2009; 190:135–141.

47. Douglas NJ, Thomas S, Jan MA: Clinical value of polysomnography. *Lancet* 1992; 339:347–350.

48. Watson PL: Measuring sleep in critically ill patients: Beware the pitfalls. *Crit Care* 2007; 11:159.

49. Figueroa-Ramos MI, Arroyo-Novoa CM, Lee KA, et al: Sleep and delirium in ICU patients: A review of mechanisms and manifestations. *Intensive Care Med* 2009; 35:781–795.

50. Ancoli-Israel S, Cole R, Alessi C, et al: The role of actigraphy in the study of sleep and circadian rhythms. *Sleep* 2003; 26:342–392.

51. Madsen MT, Rosenberg J, Gögenur I: Actigraphy for measurement of sleep and sleep-wake rhythms in relation to surgery. *J Clin Sleep Med* 2013; 9:387–394.

52. van der Kooi AW, Tulen JH, van Eijk MM, et al: Sleep monitoring by actigraphy in short-stay ICU patients. *Crit Care Nurs Q* 2013; 36:169–173.

53. Schwab K, Ronish B, Needham D, et al: Use of actigraphy to evaluate sleep in the ICU: A systematic review. *Chest* 2016; 150:217A.

54. Beecroft JM, Ward M, Younes M, et al: Sleep monitoring in the intensive care unit: Comparison of nurse assessment, actigraphy and polysomnography. *Intensive Care Med* 2008; 34:2076–2083.

55. Mion LC: Physical restraint in critical care settings: Will they go away? *Geriatr Nurs* 2008; 29:421–423.

56. Pan Y, Jiang Z, Yuan C, et al: Influence of physical restraint on delirium of adult patients in ICU: A nested case-control study. *J Clin Nurs* 2018; 27:1950–1957.

57. Jacobson SA, Dwyer PC, Machan JT, et al: Quantitative analysis of rest-activity patterns in elderly postoperative patients with delirium: Support for a theory of pathologic wakefulness. *J Clin Sleep Med* 2008; 4:137–142.

58. Honma H, Kohsaka M, Suzuki I, et al: Motor activity rhythm in dementia with delirium. *Psychiatry Clin Neurosci* 1998; 52:196–198.

59. Lipowski ZJ: Delirium in the elderly patient. *N Engl J Med* 1989; 320:578–582.

60. Lipowski ZJ: Transient cognitive disorders (delirium, acute confusional states) in the elderly. *Am J Psychiatry* 1983; 140:1426–1436.

61. Stango D, Gibson C, Breithart W: The delirium subtypes: A review of prevalence, phenomenology, pathophysiology, and treatment response. *Palliat Support Care* 2004; 2:171–179.

62. KalsiVaart KJ, Vreeswijk R, de Jonghe JH, et al: Risk factors and prediction of postoperative delirium in elderly hip-surgery patients: Implementation and validation of a medical risk factor model. *J Am Geriatr Soc* 2006; 54:817–822.

63. National Heart, Lung, and Blood Institute. Development and use of quality assessment tools. 2013. Available at: https://www.nhlbi.nih.gov/health-pro/guidelines/in-develop/cardiovascular-risk-reduction/tools. Accessed August 16, 2019.
64. Moher D, Liberati A, Tetzlaff J, et al; PRISMA Group: Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ* 2009; 339:b2535
65. Imai Y, Hasegawa K; JHKJoP: The revised Hasegawa’s dementia scale (HDS-R)-evaluation of its usefulness as a screening test for dementia. *Hong Kong J Psychiatry* 1994; 4:20
66. Gonçalves BS, Cavalcanti PR, Tavares GR, et al: Nonparametric methods in actigraphy: An update. *Sleep Sci* 2014; 7:158–164
67. Todd OM, Gelrich L, MacLullich AM, et al: Sleep disruption at home as an independent risk factor for postoperative delirium. *J Am Geriatr Soc* 2017; 65:949–957
68. Godfrey A, Leonard M, Donnelly S, et al: Validating a new clinical subtyping scheme for delirium with electronic motion analysis. *Psychiatry Res* 2010; 178:186–190
69. Leonard M, Godfrey A, Silberhorn M, et al: Motion analysis in delirium: A novel method of clarifying motoric subtypes. *Neurocase* 2007; 13:272–277
70. Godfrey A, Conway R, Leonard M, et al: Motion analysis in delirium: A discrete approach in determining physical activity for the purpose of delirium motoric subtyping. *Med Eng Phys* 2010; 32:101–110
71. Godfrey A, Conway R, Leonard M, et al: A continuous wavelet transform and classification method for delirium motoric subtyping. *IEEE Trans Neural Syst Rehabil Eng* 2009; 17:298–307
72. Godfrey A, Conway R, Leonard M, et al: A classification system for delirium subtyping with the use of a commercial mobility monitor. *Gait Posture* 2009; 30:245–252
73. Godfrey A, Conway R, Leonard M, et al: Motion analysis in delirium: A wavelet based approach for sub classification. 2008 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. Vancouver, BC, Canada, August 25–30, 2008
74. Yang CC, Hsu YL: A review of accelerometry-based wearable motion detectors for physical activity monitoring. *Sensors (Basel)* 2010; 10:7772–7788
75. Barr J, Fraser GL, Puntillo K, et al; American College of Critical Care Medicine: Clinical practice guidelines for the management of pain, agitation, and delirium in adult patients in the intensive care unit. *Crit Care Med* 2013; 41:263–306
76. Marra A, Ely EW, Pandharipande PP, et al: The ABCDEF bundle in critical care. *Crit Care Clin* 2017; 33:225–243
77. Harvey AG, Stinson K, Whitaker KL, et al: The subjective meaning of sleep quality: A comparison of individuals with and without insomnia. *Sleep* 2008; 31:383–393
78. de Souza L, Benedito-Silva AA, Pires ML, et al: Further validation of actigraphy for sleep studies. *Sleep* 2003; 26:81–85
79. Osse RJ, Tulen JH, Bogers AJ, et al: Disturbed circadian motor activity patterns in postcardiotomy delirium. *Psychiatry Clin Neurosci* 2009; 63:56–64
80. Eeles EM, Tahir TA, Johansen A, et al: Comparison of clinical assessment and actigraphy in the characterization of delirium. *J Psychosom Res* 2009; 67:103–104
81. Leung JM, Sands LP, Newman S, et al: Preoperative sleep disruption and postoperative delirium. *J Clin Sleep Med* 2013; 11:907–913