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

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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

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(24, 25). 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.

We conducted a review of the literature to learn about the current use of accelerometer devices as well as their potential applications in delirium studies. Previous studies have used accelerometer devices to 1) assess patients' sleep patterns and circadian activity rhythms to describe differences between delirious patients and nondelirious patients and 2) identify patients with delirium. We summarize the conclusions and limitations of these studies and set an agenda for the future use of accelerometer devices in the detection of delirium.

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

TABLE 1. Variables Used in Study of Circadian Activity for Delirium Studies (37, 38)

Variable	Description
Restlessness index	Addition of percentage of time moving and percentage of immobility phases of 1 min
Number of minutes immobile[a]	Total number of minutes where a score of zero was recorded
Mean activity per minute[a]	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)

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

TABLE 2. Variables Generally Used for Study of Sleep (77, 78)

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*, sleep AND delir* AND actigraph*, delir* AND actigraph* AND activity, and accelerometry 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), commentary articles (*n* = 1), and posters (*n* = 7). Combined, the studies enrolled 315 patients, with a median of 28 patients (interquartile 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

TABLE 3. Characteristics of Studies Studying Physical Activity Patterns in Delirium Patients[a]

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)[a]	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)[a]	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[b] during the first 24 hr M10[c] 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)[a]	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)[a]	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)[a]	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)[a]	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 ($MAC_{day}-MAC_{night}$)	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.

[a]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.

[b]Mean activity of the 5 hr with the lowest activity within the first 24 hr.

[c]Mean activity of the 10 hr with the highest activity within the first 24 hr.

TABLE 4. Characteristics of Studies Studying Sleep Quality Parameters in Delirium Patients

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)[a]	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[b] M10[c] 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)[a]	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 Mean awakenings (min)	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)[a]	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.

[a]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.

[b]Least active 5-hr period in the average 24-hr pattern.

[c]Most active 10-hr period in the average 24-hr pattern.

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)[a]	40[b], 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)[a]	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)[a]	40[b], 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)[a]	40[b], 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 continuous 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
Godfrey et al (72)[a]	40[b], hospice, palliative care unit patients	DRS-R-98 MDAS	Delirious: 25 Hyper: 6 Hypo: 10 Mixed: 9 Nondelirious: 9	Total summated times per sitting/lying Total summated times per standing Total summated times per stepping Number of postural transitions	The best model had accuracy of 92.3% correctly classifying delirium subtypes
Leonard et al (69)[a]	3, hospice, palliative care unit patients	DRS-R-98 MDAS	Delirious: 3 Hyper: 1 Hypo: 1 Mixed: 1	Changes in posture over 24-hr period Dynamic activity	The hyperactive patient had the most, then mixed, and the hypoactive patient had the least posture changes and dynamic activity

CWT = continuous wavelet transform, DRS-R-98 = Delirium Rating Scale-Revised-98, MDAS = Memorial Delirium Assessment Scale.

[a]All 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.

[b]Data were collected for 40 patients, data from 34 patients were included in the analysis.

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). 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.

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