Discrepancies between Objective and Subjective Sleep Assessment in Older Adults

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Abstract

Older adults are a growing segment of the population who experience disturbed sleep. In using actigraphy and self-report (e.g., sleep diaries) to measure/characterize sleep in this population, researchers have found that there is a discrepancy between these two measurement tools. Studies have found that this discrepancy is impacted by individual characteristics. The first aim of the current study was to determine the degree of congruency or differences between actigraphy and diary estimates of time spent trying to fall asleep and total time spent asleep. The second aim was to determine how individual differences in sleep quality, depressive and anxious symptoms, and memory would be associated with the difference between actigraphy and sleep diary estimates of sleep. The last aim was to determine whether the effect of sleep disturbance, depression, or anxiety on the discrepancy between the two measures was dependent on age. Our results demonstrated that participants perceived taking longer to fall asleep and sleeping more than what was indicated from an objective measure of their sleep. We found that worse sleep quality predicted a greater incongruence between self-reported and actigraphy estimated sleep onset latency. Future studies should continue to investigate how psychological and physiological functioning and processes impacts the discrepancy between self-reported and actigraphy estimated sleep in older adults and explore the longitudinal pattern of this discrepancy.

Keywords: Older adults, actigraphy, sleep diary.

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Introduction

A majority of older adults experience disturbed sleep due to age-related changes in sleep patterns, life situation (e.g., loss of partner or spouse, changes in housing, financial distress), and health status (Foley, Ancoli-Israel, Britz, & Walsh, 2004; Maggi et al., 1998; Suzuki, Miyamoto, & Hirata, 2017). To understand changes in sleep patterns, researchers and clinicians have used tools such as actigraphy and sleep diaries to assess sleep in this population. However, many studies have demonstrated that there is a discrepancy between actigraphy estimated and self-reported sleep in older adults such that individuals report spending more time awake and less time asleep as compared to actigraphy data. Although this discrepancy is often considered an expected occurrence in sleep assessment and is often accepted as a part of the data collection process, it is important to consider reasons why the discrepancy exists within an older adult population, how these factors impact sleep outcomes in older adults, and how clinicians and researchers that assess sleep and treat disorders should account for these discrepancies.

The current study explored how actigraphy estimates of sleep differed from sleep diary estimates of sleep in older adults. More specifically, we explored potential predictors of this difference such as sleep disturbance, mood, anxiety, and cognition, specifically memory. These variables have been shown to impact actigraphy and self-report differently, and the differential influence of each factor on actigraphy and self-report may drive the discrepancy between the two measurement tools in this population (Harvey & Tang, 2012). The clinical and research implications of factors that impact sleep data collected from actigraphy and self-report and the impact of such factors on sleep outcomes (e.g., sleep efficiency, sleep quality) are discussed. Recommendations for how clinicians and researchers should approach selecting a sleep measurement tool, data interpretation, and approach to the treatment of sleep disorders are

provided. Finally, we discussed future directions for research examining the discrepancy between self-report and actigraphy among older adults.

Sleep in Older Adults

Sleep is an active, non-dormant process. It is a type of circadian rhythm, that is, a pattern of behavioral and physiological functioning that occurs during a 24-hour period. It is regulated by various endogenous (e.g., neurological pathways, hormones) and exogenous (e.g., light exposure) mechanisms and factors (Zee et al., 2014). Sleep is a critical component of many cognitive, biological, and psychological functions such as memory consolidation, physiological restoration, and the maintenance of psychological well-being. The consequences of impaired sleep are numerous, and include increased mortality and morbidity, fatigue, impaired cognition, and difficulty with mood, behavior, occupation, and interpersonal relationships (Mai & Buysse, 2008; Ohayon & Reynolds, 2009). Notably, recent work has demonstrated that individuals who experience impaired sleep are also at an increased risk of developing Alzheimer's disease and dementia and experiencing non-age related cognitive decline (de Almondes, Costa, Malloy-Diniz, & Diniz, 2016; Spira, Chen-Edinboro, Wu, & Yaffe, 2014). Given the significant role of sleep in the maintenance of health and the detrimental impact of its disruption, a large body of research has focused on exploring sleep disruption and its impact on child and adult populations. More recently, increasing focus has been given to sleep disturbance in older adults due to the many unique challenges that this population faces in obtaining non-disrupted and non-impaired sleep.

In the United States, older adult age is typically defined as age 60 and older (Bartels & Naslund, 2013; Gorman, 1999). A common misconception regarding sleep in older adults is that the need for sleep decreases with increasing age. Research has demonstrated that the amount of

sleep needed by older adults to maintain optimal functioning and good health remains the same from adulthood through older adulthood (Ancoli-Israel, 2004; Neikrug & Ancoli-Israel, 2010; Roepke & Ancoli-Israel, 2010). The National Sleep Foundation recommends seven to nine hours of sleep per night for adults and seven to eight hours of sleep per night for older adults (Hirshkowitz et al., 2015). Therefore, age-related changes in sleep are not due to a reduced need for sleep and are not a component of healthy aging. Rather, these changes are due to disruptions in the *ability* to sleep (Rodriguez, Dzierzewski, & Alessi, 2015). Approximately 50% of older adults report having difficulty with sleep and 20-40% of older adults report having difficulty initiating (i.e., falling asleep) or maintaining sleep (i.e., fragmented sleep due to awakenings during the night) (Gooneratne & Vitiello, 2014; Vitiello, Larsen, & Moe, 2004). Sleep disturbance prevalence rates are higher in older women than older men (van den Berg et al., 2009). There are multiple reasons why the ability to sleep may be disturbed. The most well understood causes of disturbed sleep in older adults include biological and psychological changes.

In their review of age-related changes in sleep, Neikrug and Ancoli-Israel (2010) discuss how changes in sleep architecture (e.g., less time spent in slow wave sleep) and circadian rhythm disruptions (e.g., changes in internal and external cues for sleep) result in greater complaints of poor sleep in older adults. An increase in health concerns and co-morbid conditions may also contribute to disrupted sleep in this population (Suzuki et al., 2017; Vitiello, Moe, & Prinz, 2002). Additionally, Buysse (2004) suggests that individuals experiencing symptoms of depression or anxiety report having difficulty falling asleep and staying asleep, and that this relationship between mood and sleep is bidirectional. Given the importance and increasing interest in age-related changes in sleep and relevant psychological and physiological health

outcomes, it is important to characterize sleep in older adults using appropriate sleep measurement tools.

Measuring sleep in older adults. The three most common ways of measuring sleep in research and clinical practice are polysomnography (PSG) study, actigraphy, and self-report. A PSG study is an overnight sleep evaluation that involves the measurement of biophysiological changes using electrodes that are attached to various parts of the body, such as the scalp (Littner et al., 2003). Actigraphy measures sleep through the use of a wrist-watch like device that detects wakefulness and sleep through the presence and absence of movement (i.e., accelerometry) (Martin & Hakim, 2011). Self-reported sleep is most commonly assessed using sleep diaries, in which individuals indicate when they fell asleep and woke up over consecutive days (Libman, Fichten, Bailes, & Amsel). Whereas the administration and data processing for a PSG study requires a trained PSG technician who has completed a certified neurophysiology training program, actigraphy and sleep diary data collection and processing does not require personnel to obtain any formal certification. Additionally, these two methods allow for sleep to easily be measured across various contexts and multiple time points (Blackwell et al., 2008). Although PSG is considered the "gold-standard" of sleep assessment, many clinicians and researchers have begun to rely on and primarily use actigraphy and self-report to measure sleep due to the low cost and minimal burden.

There are multiple benefits to using actigraphy in both clinical and research settings (Ancoli-Israel et al., 2015). In addition to being small, lightweight, and similar in size and shape to a wrist-watch, actigraphy monitors also have the capacity to record sleep data across multiple days in different environments (e.g., individual's home and sleep laboratory) because the devices have disposable or rechargeable batteries and memory storage. PSGs are primarily used to

evaluate one night of sleep because they are more invasive and require the use of electrodes and other equipment to measure electrophysiological changes in a sleep laboratory (Littner et al., 2003; Newell, Mairesse, Verbanck, & Neu, 2012). Actigraphy monitors are also more economical than PSGs: the cost of using an actigraphy monitor is considerably lower than the cost of a sleep evaluation conducted using PSG (Ancoli-Israel et al., 2003). Additionally, PSG requires the presence of a trained technician to place electrodes and to process the data collected. Actigraphy needs only to be placed on an individual and the individual be given instructions regarding its use and wear. These devices are also more familiar to people given their popularity and the burgeoning field of consumer wearable technologies (e.g., Fitbit). Overall, using PSGs to evaluate sleep is often more expensive, limiting, and cumbersome than using actigraphy.

Sleep diaries are another common method used to quantify sleep. They can be completed on paper or electronically across multiple days and across multiple locations (Blake & Kerr, 2010). Importantly, sleep diaries evaluate a person's perception of their sleep. The ability to evaluate a person's subjective experience of their own sleep cannot be evaluated using PSG or actigraphy. This subjective experience of sleep, especially as it relates to sleep disturbance, is important for the diagnosis of sleep disorders such as insomnia (American Academy of Sleep Medicine, 2014; American Psychiatric Association, 2013). Before completing sleep diaries, individuals are instructed on how to self-report on various sleep parameters that are of clinical and research interest (Carney et al., 2012). Individuals typically self-report the time they went to and left bed, the time they fell asleep and woke up, how long it took them to fall asleep, how many awakenings they had during the night, how much time they spent awake during the night, and their total amount of sleep that night (Carney et al., 2012; Libman et al., 2000). It is important to note that actigraphy is not necessarily superior to sleep diaries. Subjective sleep

quality is necessarily measured through self-report and cannot be inferred through objective measures. In addition to gaining a better perspective of how a person believes they are sleeping, sleep diaries can also be used to corroborate PSG and actigraphy data and provide a richer understanding of a person's sleep experience (Ancoli-Israel et al., 2015).

In sum, both actigraphy monitors and sleep diaries allow clinicians and researchers to monitor and quantify sleep across multiple settings and days. Both measurement tools are minimally invasive and have low user burden when compared to PSG. The flexibility and ease of use of both sleep diaries and actigraphy monitors is particularly important when working with older adult populations that may have barriers (e.g., only able to sleep at home or care facility, physical limitations, lack of social support or economic means to go to a sleep center) which may prohibit their participation in an overnight sleep evaluation in a sleep laboratory.

Discrepancy between actigraphy and self-reported estimates of sleep. An increasing number of studies have reported discrepancies between sleep diary and actigraphy estimates of sleep among older adults. Specifically, researchers have found that actigraphy estimates of sleep onset latency, the amount of time it takes for one to fall asleep, and total sleep time are often lower than self-report. Additionally, actigraphy estimates of wake after sleep onset are higher than self-report (Dautovich, McCrae, & Rowe, 2008; Girschik, 2012; Kay, Buysse, Germain, Hall, & Monk, 2015; Kay, Dzierzewski, Rowe, & McCrae, 2013; Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008). These differences are more pronounced in individuals diagnosed with insomnia or reporting sleep disturbance (Manconi et al., 2010). Additionally, research has found that treating sleep disturbance reduces the discrepancy between actigraphy and sleep diary estimates of sleep, and participants who do not report sleep disturbance demonstrate greater congruence between actigraphy and sleep diary data (Kay et al., 2015). This suggests that the

discrepancy between the two measures may be a sign of having difficulty with sleep. Therefore, it is important to consider the discrepancy between the two tools when examining sleep in older adults. This population experiences age-related changes in sleep that can impact and is also impacted by psychological and physiological health.

The well-established difference between actigraphy and sleep diaries has caused many researchers and clinicians to question what tools to use when assessing sleep in older adults and to consider factors that may contribute to the discrepancy between the two sleep measurement techniques. It has also led researchers and clinicians to consider how their sleep data are biased by individual characteristics (Girschik, 2012; Williams, Kay, Rowe, & McCrae, 2013). Although researchers have found that reports of poor sleep (e.g., poor sleep quality, symptoms of insomnia, more variability in sleep, and greater reports of napping) may be a cause of this discrepancy, few studies or reviews have synthesized and explored additional reasons *why* these discrepancies in self-reported and actigraphy estimates of sleep exist in older adults (Kushida et al., 2001; Manconi et al., 2010; McCrae et al., 2005). Based upon what is known about the limitations of actigraphy and self-report as sleep measurement tools, there are other reasons beyond poor sleep, such as psychological factors that may account for the differences between actigraphy calculated and self-reported sleep in older adults.

Why Do Actigraphy and Sleep Diary Estimates of Sleep Differ?

There are numerous potential explanations for discrepancies between objective and subjective estimates of sleep. The measures themselves have inherent biases, such as relying on lack of movement to indicate sleep for actigraphy and self-report bias for sleep diaries. In addition to the biases inherent in the measurement tools themselves, there are several factors that have been identified as contributing to the discrepancy between actigraphy and sleep diary data.

The factors are having difficulty with sleep, depression, anxiety, and cognition (i.e., memory). These factors are described in more detail below and can be seen in Figure 1 (pg. 59).

Difficulty with sleep. Many older adults have difficulty with sleep (Gooneratne & Vitiello, 2014; Rodriguez et al., 2015; Vitiello et al., 2004). Sleep difficulties are often a result of psychological or physiological changes and are not considered part of typical aging (Williams et al., 2013). Common examples of sleep difficulties include the presence of a sleep disorder (e.g., insomnia, sleep apnea), having trouble falling and staying sleep, and experiencing early morning awakenings, non-restorative sleep, poor sleep quality, and fatigue (LeBlanc et al., 2007; Mai & Buysse, 2008; Ohayon, 2002). These sleep difficulties have been found to contribute to the discrepancies between objective and subjective measures of sleep in older adults (Edinger & Krystal, 2003; Harvey & Tang, 2012). When comparing PSG to self-reported sleep data in adults and older adults with and without insomnia, individuals experiencing insomnia self-reported lower total sleep time and taking longer to fall asleep than PSG estimates when compared to participants without insomnia (Bianchi, Williams, McKinney, & Ellenbogen, 2013; Blackwell et al., 2008; Frankel, Coursey, Buchbinder, & Snyder, 1976; Manconi et al., 2010). Therefore, sleep difficulties can be observed in subjective measures of sleep (i.e., individuals reporting that they are not sleeping well) and can contribute to the discrepancy between objective and subjective measures of sleep. The discrepancy between objective and subjective measures of sleep is not only limited to the relationship between PSG and sleep diary data; this discrepancy between objective and subjective measures of sleep has also been observed when comparing actigraphy and sleep diary data.

Compared to older adults who do not report disturbed sleep or insomnia, older adults (mean age 71.93 years-old) who self-identify as having problematic sleep report waking more

frequently and spending more time awake than evidenced by their actigraphy data (Williams et al., 2013). Notably, the correlation between actigraphy and sleep diary data is predictive of complaints of poor sleep and severity of sleep disturbance, with a lower correlation between the two measures indicating worse subjective sleep (McCrae et al., 2005). Older adults experiencing sleep difficulty also demonstrate greater variability in the discrepancy between the two measures across time. That is, individuals may have more pronounced differences between actigraphy and sleep diary data on some nights than others. This variability is related to quality of sleep. This indicates that the discrepancy between both measures of sleep is not a constant value and instead changes across time (Kay et al., 2013). These studies demonstrated that older adults with sleep problems self-report poorer sleep than what is indicated by objective measures. Having difficulty with sleep is related to a greater discrepancy between actigraphy and sleep diary data, which raises the question of whether reducing sleep difficulty would lead to a greater concordance between the two measures of sleep.

The degree to which sleep appears to improve following treatment varies depending on whether actigraphy or sleep diary data is considered. In their study that examined the impact of an insomnia treatment for older adults (age range: 60-79 years-old, mean age: 67.7 years-old), Brooks, Friedman, Bliwise, and Yesavage (1993) found that subjective reports of improved sleep were greater than results objectively measured with actigraphy. Participants self-reported an increase in total sleep time following treatment, but actigraphy data demonstrated that participants had significantly reduced total sleep time at the end of treatment. Although not statistically tested, Brooks et al. (1993) reported a larger discrepancy between actigraphy and sleep diary data in their sample of older adults prior to treatment than following treatment, suggesting that reducing symptoms of insomnia (e.g., improving subjective sleep) may reduce

the discrepancy between actigraphy and sleep diary data. These results are consistent with studies using adult samples (18-60 years-old) diagnosed with insomnia. After participating in an intervention to reduce the discrepancy between actigraphy and sleep diary data, participants self-reported fewer insomnia symptoms and had greater reductions in the discrepancy between the two measures than those that did not receive the intervention (N.K. Tang & A.G. Harvey, 2004; Tang & Harvey, 2006). Kay et al. (2015) also compared actigraphy and sleep diary data in older adults before and after an insomnia treatment protocol. Like Brooks et al. (1993), they found that prior to being treated for insomnia, older adults (mean age of 67.7 years-old) diagnosed with insomnia demonstrated a greater difference between actigraphy and sleep diary data than older adults without disturbed sleep. Importantly, following treatment these individuals reported a reduction in insomnia severity and demonstrated a significant reduction in the discrepancy between their actigraphy and sleep diary data as compared to their pre-treatment data. These results confirm the notion that self-identifying as a poor sleeper is related to perceptions of sleeping less and spending more time awake at night than what is objectively demonstrated. Importantly, this phenomenon has been observed in both younger and older adults.

Summary. Clinicians and researchers who rely solely on actigraphy to capture sleep in this population may not observe sleep difficulties unless they ask individuals to report on their sleep. Older adults who are having sleep difficulty may appear to be sleeping well if sleep is only measured with actigraphy. If both sleep diaries and actigraphy data are collected and a discrepancy is observed but not understood, this could lead to the trivialization of sleep disturbance in older adults by clinicians and researchers. However, the discrepancies observed are not merely an artifact of the measurement tools used or the population being studied and treated. Given that the discrepancy between actigraphy and sleep diary data is quite common and

can be misconstrued, it is important to continue to examine the relationship between this discrepancy and poor sleep.

The effects of sleep problems on the discrepancy between actigraphy and sleep diary data are known and are not unique to older adults. Older adults having trouble with sleep have greater discordance between actigraphy and sleep diary data such that they report spending more time awake and less time asleep than indicated by actigraphy data. In this respect, older adults look much like other adult populations with sleep disturbance who also underestimate their time spent asleep and overestimate the time they spend awake as compared to actigraphy estimates (Manconi et al., 2010). This suggests that this association between sleep difficulty and the discrepancy between the two measures can be observed across a large age range. However, there are still gaps in our knowledge of this association. It is unclear if the association between sleep disturbance and the discrepancy between actigraphy and sleep diary data may change with increasing age. Even though we know that sleep disturbance is associated with the discrepancy between actigraphy and sleep diary data, it is unknown how this relationship may change when other variables are considered. These variables include individual characteristics such as mood, anxiety, and cognition, which are known to impact the discrepancy between actigraphy and sleep diary data.

Psychological factors. Many older adults experience their first symptoms or diagnosis of depression when they are 60 years old or older. Symptoms of depression are more prevalent in older adult women than in older adult men (Kockler & Heun, 2002; Vafaei, Ahmed, Freire, Zunzunegui, & Guerra, 2016). Approximately 15% of older adults endorse symptoms of depression and between 1 to 5% meet criteria for a diagnosis of depression. These prevalence rates are lower in older adults than younger and middle aged adults due to differences in

presentation between the two groups, difficulty in evaluating depression in older adults, and expectations regarding aging (Fiske, Wetherell, & Gatz, 2009). Anxiety is also common among older adults, with between 15 to 52% of older adults endorsing symptoms of anxiety and 1 to 28% meeting criteria for an anxiety diagnosis (Bryant, Jackson, & Ames, 2008). These prevalence rates are similar to those of community dwelling adults (Bandelow & Michaelis, 2015). Like depression, anxiety prevalence rates are higher in older adult women than men (Reynolds, Pietrzak, El-Gabalawy, Mackenzie, & Sareen, 2015). It is hypothesized that anxiety is more prevalent than depression in older adults because of increased concerns regarding declining physical and mental health (Bryant et al., 2013). Depression and anxiety are believed to negatively impact cognitive functioning (Bryant et al., 2013; Fiske et al., 2009). Endorsing more symptoms of depression and anxiety have been linked to difficulty with memory, attention, inhibition, and ability to shift focus in older adults (Beaudreau & O'Hara, 2009; Gotlib & Joormann, 2010). Importantly, all three factors (depression, anxiety, and cognition) have been found to contribute to the discrepancies between actigraphy and sleep diary estimates of sleep. These factors are especially interesting to consider when discussing the discrepancy between the two measures in older adults given that depression and anxiety are highly prevalent in older adults and that difficulties with cognition increase with age (Hugo & Ganguli, 2014).

Depression and anxiety. A large body of literature has investigated the impact of depression and anxiety on sleep. Overall, researchers have found that higher levels of anxiety and depression are associated with poor subjective sleep (Buysse, 2004; Uhde, Cortese, & Vedeniapin, 2009). Similar to the adolescent and adult literature, researchers have found that older adults (55-85 years-old) who self-reported more symptoms of depression and anxiety also had more self-reported complaints of poor sleep (Maggi et al., 1998; Spira et al., 2008). Older

adults with mood disturbance also demonstrated worse sleep as measured through actigraphy. Older adults (65 years-old and older) who self-reported many symptoms of anxiety also demonstrated lower sleep efficiency (ratio of total time spent asleep to time spent in bed) and a greater amount of time spent awake after sleep onset as measured through actigraphy (Martin & Hakim, 2011; Spira, Stone, Beaudreau, Ancoli-Israel, & Yaffe, 2009). Additionally, older adults (70 years-old and older) who self-reported more symptoms of depression also exhibited lower sleep efficiencies, spent more time trying to fall asleep, and spent more time awake after sleep onset as measured through actigraphy (Maglione et al., 2012). Because both measurement tools demonstrate similar relationships to mood (i.e., more symptoms of depression/anxiety reported, worse actigraphy and self-reported sleep), it would be tempting to assume that there would be no discrepancy between the two sleep tools or that the discrepancy between the two tools is not important. However, research has demonstrated that more self-reported symptoms of depression and anxiety are related to a greater discrepancy between the two tools.

Depression has been found to play a similar role as sleep difficulty in impacting the difference between actigraphy and sleep diary estimates of sleep. Older adults (60 years-old and older) that report more symptoms of depression have greater discrepancies between actigraphy and self-reported sleep (Kay et al., 2015). Higher levels of depression are associated with self-reported total sleep times that are lower than actigraphy total sleep times (Van Den Berg et al., 2008). Baillet et al. (2016) examined the discrepancy between sleep diary and actigraphy in older adults (mean age 75 years-old) with respect to depressive symptomatology, finding that the difference between actigraphy and sleep diary estimates of sleep was explained by the number of symptoms of depression participants endorsed when they completed sleep diaries. They also determined that participants who reported many symptoms of depression underestimated how

much time they spent asleep. Baillet et al. (2016) also examined the role of positive mood. They found that participants who reported a more positive mood also had a smaller discrepancy between actigraphy and sleep diary data. Self-reported symptoms of anxiety have been found to be related to a bigger difference between actigraphy data and sleep diary estimates of sleep (N. K. Tang & A. G. Harvey, 2004). Older adults (mean age 73 years-old) who endorsed more symptoms of anxiety and depression had a greater discrepancy between actigraphy and sleep diary data. These participants reported sleeping poorly in their sleep diaries. However, when compared to their actigraphy data, participants objectively spent less time awake and more time asleep when compared to their sleep diary data (McCrae et al., 2005). In sum, these studies demonstrated that depression and anxiety influenced the discrepancy between actigraphy and sleep diary data. Higher levels of depression and anxiety are related to a greater discrepancy between the two measures of sleep. Participants with symptoms of depression and anxiety tend to underestimate sleep and overestimate time spent awake as compared to their actigraphy data.

In studies that have compared PSG studies to sleep diaries, researchers have found that higher levels of anxiety are related to a greater discrepancy between PSG estimates and sleep diary reports of sleep. For example, adults that report more symptoms of anxiety and adults that have “anxious personalities” also report more time spent awake and less time spent asleep than what was demonstrated in their PSG data (Fernandez-Mendoza et al., 2011; Riedel, Winfield, & Lichstein, 2001). Although these studies and those comparing actigraphy to sleep diary data did not use older adult populations, they provide a foundation for future work involving older adults.

Memory. Psychological processes beyond mood may also contribute to the discrepancy between actigraphy and self-report. An important variable to consider when discussing sleep and the discrepancy between actigraphy and sleep diary measurement tools in older adults is

cognition, specifically memory. Research has demonstrated that memory is an especially important domain of cognition to measure in healthy older adults (Weintraub et al., 2017). Significant declines in memory distinguish older adults experiencing age-related changes in memory from older adults experiencing cognitive impairment: older adults with cognitive impairment perform significantly worse on tasks related to delayed recall than healthy older adults (Salmon & Bondi, 2009). Delayed recall tasks are also considered "sensitive indicator[s] of memory loss" (Craft et al., 1996). Memory may influence older adults' ability to accurately self-report their sleep given that it is a task that involves recalling the time they went to sleep and woke up. In their study comparing actigraphy estimated and self-reported time in bed and nighttime awakenings in veterans diagnosed with post-traumatic stress disorder (PTSD), Westermeyer et al. (2007) found that participants who reported having difficulty with cognition and/or memory due to substance use or sleep disturbance had difficulty completing sleep logs. They also suggested that participants may not have remembered, and therefore not reported, nighttime awakenings due to PTSD related memory impairment. Memory is especially important to consider when sleep is evaluated across multiple time points. Harvey and Tang (2012) suggest that participants' memory of their sleep patterns can bias self-reported sleep. If participants are asked to self-report sleep across multiple days, they may be evaluating their sleep by comparing it to other nights of sleep they have had. For example, they may recall the amount of time it took them to fall asleep or amount of time they spent asleep by reflecting on their most recent night of sleep or the worst/best sleep they had during the reporting period. To our knowledge, there is a paucity of research investigating the relationship between memory and the discrepancy between actigraphy estimated and self-reported sleep in older adults. A majority of the research has focused on the relationship between the discrepancy and dementia/global cognitive impairment.

Reviewing the literature regarding dementia/cognitive impairment and the discrepancy between actigraphy estimated and self-reported sleep can shed light on the relationship between memory and the discrepancy because memory is a component of dementia/cognitive impairment. It is common to observe sleep disturbance in older adults with symptoms of dementia. Older adults (mean age 65.6 years-old) that exhibit symptoms of dementia and demonstrate greater beta-amyloid deposition (a biological marker found in those diagnosed with Alzheimer's disease), spend more time in bed awake than asleep, as measured by actigraphy, and thus exhibit worse objective sleep than older adults without dementia (Ju et al., 2013). When comparing PSG sleep data and self-reported sleep in older adults with (mean age 67.1 years-old) and without mild cognitive impairment (mean age 70.5 years-old), Hita-Yañez, Atienza, and Cantero (2013) observed a significant difference between the two measures only in those with mild cognitive impairment: self-reported sleep onset latency was higher than PSG sleep onset latency in this group. They concluded that impaired memory was driving this discrepancy because memory plays a significant role in the retrospective estimation of time. Additionally, neuropathways associated with memory and the recollection of time are impaired in older adults with mild cognitive impairment who then develop Alzheimer's disease. When comparing self-reported total sleep time to actigraphy estimated total sleep time in older adults, Van Den Berg et al. (2008) found that the discrepancy between the two measures increased with greater global cognitive impairment (i.e., poorer performance on the Mini Mental Status Exam) in their sample of older adults (57-97 years-old, mean age 68.5 years-old). Cognitive decline was associated with poor objective sleep and the discrepancy between actigraphy and sleep diary data. Participants with greater cognitive impairment may have been less reliable reporters because of global decline in cognitive functioning. Similar to the discrepancy observed when taking into

account mood and recall bias, the incongruence between the two measures was because older adults with greater cognitive impairment self-reported spending more time awake and less time asleep than actigraphy estimates. However, this effect is not entirely consistent across studies. Landry, Best, and Liu-Ambrose (2015) found no significant association between cognition (as measured by the Montreal Cognitive Assessment) and differences between actigraphy and sleep diary estimates of sleep. Trends suggested that participants overestimated the time they spent awake and underestimated time spent asleep compared to actigraphy estimates. The inconsistency between these two studies is likely attributable to differences in the sample and measure of cognition. Compared to the Van Den Berg et al. (2008) study, Landry and colleagues (2015) older adult sample (55-83 years-old, mean age 71.6 years-old) was relatively healthy and cognitively intact, which could explain why they observed no significant association between cognition and discrepancy between actigraphy and sleep diary.

Although the two studies cited did not conclusively show that cognitive impairment was significantly related to a greater discrepancy between actigraphy and sleep diary data, these studies did demonstrate the importance of taking into consideration the established relationship between age, cognitive decline, and sleep disturbance when considering discrepancies between the two measurement tools. Additionally, it would be more helpful to administer more detailed cognitive assessments that might be more illuminating regarding the relationship between specific domains of cognition and discrepancy between the two measurement tools. Both the Mini Mental Status Exam (MMSE) and Montreal Cognitive Assessment (MoCA) provide global assessments of cognitive impairment and mental status. The MMSE is comprised of 30 questions that assess the following domains: 1) Orientation, 2) registration, 3) attention, 4) calculation, 5) recall, and language (Folstein, Folstein, & McHugh, 1975). The 12 sets of questions on the

MoCA assess the following domains: 1) Visuospatial abilities, 2) executive functioning, 3) language, 4) memory, 5) attention, 6) concentration, and 7) orientation (Nasreddine et al., 2005). On both instruments, lower scores indicate greater cognitive impairment (Folstein et al., 1975; Nasreddine et al., 2005). Compared to the MMSE, the MoCA has better sensitivity and specificity in detecting mild cognitive impairment and mild AD in older adults (Nasreddine et al., 2005). This suggests that the MoCA is a better tool than the MMSE in the assessment of cognitive impairment. However, these mixed findings indicate that it is important to not only measure global cognitive impairment and mental status, but to hone in on memory when measuring cognition in healthy older adults.

Summary. The previously reviewed research has demonstrated that, in addition to sleep disturbance, the lack of concordance between actigraphy and sleep diary data can be explained by individual characteristics; mood and cognition can greatly influence the perception and reporting of sleep. Depression and anxiety appear to have effects on both subjective and objectively measured sleep. Among older adults, depression and anxiety are related to greater differences between sleep diaries and actigraphy. Older adults that report many symptoms of depression and anxiety also report sleeping less and spending more time awake compared to actigraphy estimates of wake and sleep. In contrast, positive mood is related to a greater congruence between the two measurements. This effect, like that of disturbed sleep, appears in the general adult population as well as in older adults. This indicates that the relationship between depression and anxiety and the discrepancy between actigraphy and sleep diary data does not change with age; across time, higher levels of depression and anxiety are related to a greater difference between the two measures. Although not cohesive, the studies reviewed have demonstrated that global cognitive impairment can impact self-reported sleep: greater levels of

cognitive impairment may be related to participants reporting more time spent awake and less time spent asleep as compared to actigraphy. However, there is a lack of research that looks at the specific effect of memory on the discrepancy between self-reported and actigraphy estimated sleep. Research suggests that it may be more informative to examine specific domains of cognition such as memory in healthy older adults who may not exhibit global cognitive decline. Therefore, when considering predictors of the discrepancy between actigraphy and sleep diary data, it is important to include the effects of depression, anxiety, and memory, along with sleep disturbance.

The difference between actigraphy and sleep diary is not merely a product of measurement error nor should it be regarded as simply an anomaly in the data. In addition to sleep disturbance, older adults may be experiencing symptoms of depression for the first time in older age and are at greater risk for cognitive impairment than younger populations. They also may be experiencing symptoms of anxiety (Bryant et al., 2008; Bryant et al., 2013; Fiske et al., 2009; Hugo & Ganguli, 2014). We know that depression, anxiety, and cognition are associated with the discrepancy and are relevant to older adults. However, it is unknown if the effect of depression, anxiety, and cognition on the discrepancy between actigraphy and sleep diary data changes with increasing age.

Other factors. It is worth noting that there are other possible variables that influence the discrepancy between actigraphy and sleep diary estimates of sleep that are relevant to older adults. These variables include, but are not limited to, physiological functioning and pre-sleep arousal. Physiological functioning includes self-reported pain and physical movement, two variables that are known to influence subjective and objective measures of sleep (Lunde, Pallesen, Krangnes, & Nordhus, 2010; Martin & Hakim, 2011). Pre-sleep arousal refers to a state

of “activation and/ or agitation” prior to going to sleep (Harvey & Tang, 2012). It includes both cognitive and physiological processes, such as muscular tension, increased heart rate, being “mentally alert,” and racing thoughts (Nicassio, Mendlowitz, Fussell, & Petras, 1985). Although these variables are known to impact the discrepancy between actigraphy and sleep diary estimates of sleep, these data are not available for the current study. However, these variables are considered when discussing the results, implications, and limitations of the current study.

Current Study

There are multiple predictors of discrepancies between actigraphy and sleep diary measures of sleep in older adults. These explanations include having difficulty with sleep, mood, anxiety, and cognition, as well as assumptions made by actigraphy about the relationship between movement and sleep and biases associated with self-report sleep diaries. Experiencing poor sleep, symptoms of anxiety and depression, and impaired cognition are related to greater incongruence between actigraphy and sleep diary data, specifically underestimates in self-report compared to actigraphy estimates of sleep. It is important to study how these individual characteristics in older adults interact and influence the relationship between actigraphy and sleep diary data because it impacts how clinicians and researchers interpret and make clinical decisions about sleep data. It can also impact how sleep in older adults is treated and conceptualized as well as older adults’ treatment seeking behaviors.

The primary objective of the current study was to explore the difference between actigraphy and sleep diary estimates of sleep in older adults. Aim 1 was to determine the degree of congruency or differences between actigraphy and diary estimates of time spent trying to fall asleep and total time spent asleep. Consistent with previous literature, we hypothesized that on

average, participants would self-report spending more time awake and less time asleep compared to actigraphy estimates of their sleep.

Aim 2 was to evaluate how individual differences would be associated with the difference between actigraphy and sleep diary estimates of sleep. The individual differences of interest included sleep quality, depressive and anxiety symptoms, and cognition, specifically memory. Because each participant provided daily actigraphy and sleep diary data, we included these individual factors in a multilevel regression model to determine the association between each of these variables with the difference between actigraphy and sleep diary data. Given that our sample was comprised of male and female older adults that are between 60 to 89 years-old, age and gender were included as covariates. We hypothesized that disrupted sleep, mood, meeting criteria for an anxiety diagnosis, and memory would significantly predict the discrepancy between actigraphy and sleep diary data.

Previous research studying predictors of the discrepancy between actigraphy and sleep diary data in older adults have rarely included interactions to understand how these effects may differ by age. Thus, Aim 3 of the current study was to explore how age and the other individual characteristics interact to predict the discrepancy between actigraphy and sleep diary data. We explored these associations by including three interaction terms in the multilevel model: age and sleep disturbance, age and depression, and age and anxiety. This allowed us to determine if the effect of sleep disturbance, depression, or anxiety on the discrepancy is dependent on age.

A difference between actigraphy and sleep diary data in our sample would indicate that the discrepancy between subjective and objective measures of sleep is a common phenomenon in older adults that researchers and clinicians need to consider. The modality of sleep measurement would thus be an important variable to consider when conducting both clinical and research

work. If having more disrupted sleep, worse mood and anxiety, and more impaired cognition is found to be related to worse sleep as measured by actigraphy and sleep diary data and greater discrepancy between the two measures, this would replicate previous findings and emphasize the importance of continuing to consider and measure individual characteristics when assessing sleep in older adults. If the relationship between age and discrepancy between actigraphy and sleep diary data is found to be moderated by disrupted sleep, mood, and/or anxiety, this would suggest that the strength of the relationship between age and difference between the measures is affected by an individual's sleep, depressive symptomatology, and/or level of anxiety.

Methods

Recruitment and Participants

The current study was a secondary analysis of data collected from participants that were recruited from the University of Kansas Alzheimer's Disease Center Registry (KU-ADC) between June 2015 through January 2018. This is a large registry of well-characterized Alzheimer's disease (AD) patients and older adult controls without cognitive impairment. Recruitment and evaluation procedures conducted at the KU-ADC have been described previously (Graves et al., 2015). Briefly, registry participants receive cognitive testing and clinical examinations annually. Experienced study clinicians trained in dementia assessment and clinical research provide consensus diagnoses through a comprehensive clinical research evaluation and review of medical records. Diagnostic criteria for AD follow NINCDS-ADRDA criteria (McKhann et al., 1984). Participants who had undergone full physical and neurological examinations and a review of medical history were recruited from the registry to participate in a study exploring physical activity and sleep using a wrist worn actigraphy monitor. The parent study sample included individuals with mild AD based on clinical dementia rating (CDR) scale

scores of 0.5 (very mild) or 1 (mild) and older adult controls with CDR scores of 0 (normal) (Morris, 1993). Given that we are interested in older adults without cognitive impairment, only participants with a CDR score of 0 were included in the analyses. The KU-ADC registry excludes individuals with active (<2 years) ischemic heart disease (myocardial infarction or symptoms of coronary artery disease) or uncontrolled insulin dependent diabetes mellitus. The study protocol was approved by the KU Medical Center Human Subjects Committee. Participants, and/or their legally acceptable representative, provided written, informed consent.

Measures

Actigraphy. Participants were asked to wear an actigraph (ActiGraph, LLC, GT9X, Pensacola, FL) on their non-dominant wrist for seven days. Because the device is waterproof, participants were instructed to always wear it including during showering, bathing, or swimming. An actigraph is a small, wrist-watch like device that was used to record movement across seven for 24-hour periods. Actigraphy has been used as a valid measure of objective sleep that is noninvasive with minimal participant burden (Ancoli-Israel et al., 2003; Kushida et al., 2001). ActiLife software version 6.13.2 was used to analyze the actigraphy data (ActiGraph, LLC, GT9X, Pensacola, FL). The Choi wear time validation algorithm was used to determine time periods where participants did not wear the actigraph (Choi, Liu, Matthews, & Buchowski, 2011).

Sleep diary. Participants completed paper sleep diaries for the duration of their participation. Prior to going to sleep, participants were asked to report the time and length of any naps they took that day. Participants were asked to report the following upon awakening: the time they got into bed, the time they attempted to fall asleep, how long it took them to fall asleep, the time they woke up in the morning to start their day, and the time they got out of bed to start

their day. The sleep diary also included a section for each day where participants were asked to include any comments regarding anything that may have affect their sleep such as illness, travel, or sleeping in a novel environment.

Sleep Estimate Discrepancies. The absolute difference between self-reported and actigraphy measured sleep onset latency (SOL) and total sleep time (TST) was calculated for each night by subtracting actigraphy measured SOL and TST from self-reported SOL and TST. For example:

$$\text{SOL Discrepancy}_{\text{Night1}} = |\text{SleepDiarySOL}_{\text{Night1}} - \text{ActigraphySOL}_{\text{Night1}}|$$

$$\text{TST Discrepancy}_{\text{Night1}} = |\text{SleepDiaryTST}_{\text{Night1}} - \text{ActigraphyTST}_{\text{Night1}}|$$

This method of calculating sleep discrepancy to capture the magnitude of difference between actigraphy estimates of sleep and sleep diary data is consistent with previous research (Kay et al., 2015; Van Den Berg et al., 2008). Absolute values were also used due to the distribution of the sleep estimate discrepancies (values for both SOL and TST discrepancies were negative and positive) and for ease of coefficient interpretation.

Sleep quality. The Pittsburgh Sleep Quality Index (PSQI) is a self-report questionnaire that is composed of 10 questions which assess sleep quality in the last month. From these questions, seven component scores (1) subjective sleep quality, 2) sleep onset latency, 3) sleep duration, 4) sleep efficiency, 5) sleep disturbance, 6) use of sleep medication, and 7) daytime dysfunction) and a global sleep quality score can be calculated. Global sleep quality scores can range between 0 and 21 with higher scores indicating poorer sleep quality (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). Overall, the scale has high test-retest reliability and good internal consistency and validity (Backhaus, Junghanns, Broocks, Riemann, & Hohagen, 2002; Spira et al., 2012). Because we are interested in the influence of overall sleep quality on the

discrepancy between actigraphy estimated and self-reported sleep, we used the global sleep quality score.

Mood. The Geriatric Depression Scale-Short Form (GDS-SF) is a 15 item self-report measure administered by a clinician to screen for the presence of depressive symptomatology. As part of the comprehensive clinical research evaluation, participants were asked to respond yes or no to items assessing how they have felt over the last week such as "Have you dropped many of your activities and interests?" and "Do you feel that your life is empty?" Scores can range between 1 and 15 with higher scores indicating greater symptoms of depression. Scores of 5 or less are considered normal. Overall, the scale has good reliability and validity in older adult populations (Sheikh & Yesavage, 1986).

Anxiety. As part of the comprehensive clinical research evaluation and review of medical records, a clinician assessed for the presence of an anxiety disorder in participants using criteria outlined by the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM5) (American Psychiatric Association, 2013). Although researchers have stated that these criteria are often insensitive to the presence of anxiety in older adults, they are an improvement from previous versions of the Diagnostic and Statistical Manual of Mental Disorders anxiety disorder criteria (Bryant et al., 2013; Sachdev, Mohan, Taylor, & Jeste, 2015). Because we are interested in the presence or absence an anxiety disorder, this variable was coded as a categorical variable with the absence of an anxiety disorder coded as a 0 and the presence of an anxiety disorder coded as a 1.

Memory. Craft Story 21 Recall- Immediate and Delayed is a non-proprietary measure of episodic memory. Participants are told that they will be read a story and that they will be asked to repeat everything they remember from the story after it is read. After recalling the story

immediately after it is read, participants are then told to not forget the story because the administrator will ask them about the story later. Participants are asked to recall the story 20 minutes after they first heard it. The story contains 44 units that can be recalled. Each unit recalled is given a point and a total score for the immediate and delayed conditions. The following is a sentence from the story: Maria's child Ricky played soccer every Monday at 3:30. The sentence contains eight units that can be scored. Both the immediate and delayed conditions can be scored either using the verbatim or paraphrase scoring criteria. The paraphrase scoring criteria allows participants to provide multiple responses to earn points on the measure. Verbatim scoring criteria, however, only allocates points for items recalled exactly as they were presented in the story. Given that our sample is comprised of older adults without cognitive impairment, we used participants' verbatim scores because they are more sensitive to early memory decline than paraphrase scores. Scores on both the immediate and delayed conditions range from 0 to 44, with higher scores indicating better immediate and delayed memory (Craft et al., 1996; Monsell et al., 2016; Weintraub et al., 2017). Because it is unclear as to whether immediate or delayed memory influences the discrepancy between actigraphy estimated and self-reported sleep, both scores were included in our analyses.

Procedures

Once participants had undergone full physical and neurological examinations and a review of medical history, they were offered an opportunity to participate in a study exploring measuring physical activity and sleep. If they or their legally accepted representative consented to participate, participants were given an actigraph to wear and sleep diary to complete for one week. Participants were given paper instructions on how to wear the actigraph and complete the sleep diaries. They were also provided with a pre-stamped and addressed envelope to send the

actigraph and sleep diary back one week after they received it. When materials were received, sleep diary data was inputted into a database and actigraphy data were downloaded and processed according to the following procedure: sleep data files were opened in the ActiLife software and analyzed in 24-hour period view mode. A sleep interval for each day of wear was automatically added by the software. The software calculates this interval using the Cole-Kripke sleep algorithm (Cole, Kripke, Gruen, Mullaney, & Gillin, 1992). These automatically added sleep intervals were manually compared to participants' sleep diaries. For each day, the interval generated by ActiLife was used if either the participants' self-reported time they went to sleep and woke up in the morning or if the participants' self-reported time in bed and time out of bed was within 30 minutes of the ActiLife generated interval. If the interval was not within 30 minutes of the self-reported sleep time and wake time or the time in bed and out of bed, then the sleep interval was deleted (Ancoli-Israel et al., 2015). A new sleep interval was then manually added based upon the presence or absence of movement. Generally, sharp decreases in activity are indicative of sleep and sharp increases in activity are indicative of wake (Ancoli-Israel et al., 2015; Blackwell et al., 2005).

Although a majority of participants completed the full physical and neurological examinations and review of their medical history on the same day they were offered an opportunity to participate in the parent study (n= 57), some participants completed the examination and questionnaires before (n= 6, mean= 366.17 (32.98)) or after (n= 15, mean= 312.60 (84.28)) wearing the actigraph and completing sleep diaries (Figure 2). To account for the amount of time between when sleep quality, depression, and memory were assessed and when sleep was measured, the number of days between assessment and actigraphy was including as a covariate in our analyses.

Missing Data

All participants had at least three nights of complete actigraphy and sleep diary data. All participants had at least three SOL and TST absolute difference scores and provided PSQI, GDS-SF, Craft 21 Story Recall Immediate and Delayed, and Anxiety data. Therefore, there was no missing data. Because only one person in our sample met criteria for an anxiety diagnosis (Table 3), planned analyses exploring the relationship between anxiety and the discrepancy between self-reported and actigraphy estimated SOL and TST could not be conducted.

Data Analysis

Data were analyzed using IBM SPSS Statistics version 24 software (IBM Corporation). Statistical significance was determined using a p-value of .05. Descriptive statistics for the variables of interest (e.g., self-reported and actigraphy measured SOL and TST, PSQI, GDS-SF, Craft Story 21 Recall Immediate and Delayed, anxiety diagnosis) are presented in Tables 2 and 3.

Aim 1. Given the non-normal distribution of our data, we used multiple Wilcoxon Signed-Rank tests to determine if, on average, there was a significant difference between average actigraphy SOL and TST and average sleep diary SOL and TST data. The comparisons were:

1) Average Actigraphy SOL compared to Average Sleep diary SOL

2) Average Actigraphy TST compared to Average Sleep diary TST

Aims 2 and 3. Because each participant (level-2 unit) provided multiple days of actigraphy and sleep diary data (level-1 unit), and therefore had multiple SOL and TST scores, multilevel regression models were conducted to determine the relationship between individual characteristics (collected at level-2: gender, sleep quality, depression, memory, interaction between age and sleep quality, and interaction between age and depression) and the outcomes

variables (collected at level-1: the discrepancy between actigraphy estimated and sleep diary reported SOL and the discrepancy between actigraphy estimated and sleep diary reported TST). The multilevel regression model equations are presented below:

$$|\text{SOL Discrepancy}_{ij}| = \hat{\gamma}_{00} + \hat{\gamma}_{01}(\text{age}_j) + \hat{\gamma}_{02}(\text{gender}_j) + \hat{\gamma}_{03}(\text{days since testing}) + \hat{\gamma}_{04}(\text{sleep quality}_j) + \hat{\gamma}_{05}(\text{depression}_j) + \hat{\gamma}_{06}(\text{immediate memory}_j) + \hat{\gamma}_{07}(\text{delayed memory}_j) + \hat{\gamma}_{08}(\text{age*sleep quality}_j) + \hat{\gamma}_{09}(\text{age*depression}_j)) + u_{oi} + e_{ij}$$

$$|\text{TST Discrepancy}_{ij}| = \hat{\gamma}_{00} + \hat{\gamma}_{01}(\text{age}_j) + \hat{\gamma}_{02}(\text{gender}_j) + \hat{\gamma}_{03}(\text{days since testing}) + \hat{\gamma}_{04}(\text{sleep quality}_j) + \hat{\gamma}_{05}(\text{depression}_j) + \hat{\gamma}_{06}(\text{immediate memory}_j) + \hat{\gamma}_{07}(\text{delayed memory}_j) + \hat{\gamma}_{08}(\text{age*sleep quality}_j) + \hat{\gamma}_{09}(\text{age*depression}_j)) + u_{oi} + e_{ij}$$

A minimum of 50 level-2 units is considered robust enough and acceptable for conducting multilevel analyses. Our sample of 78 participants meets this criterion. (Hox, 2010; McNeish & Stapleton, 2016). Given the number of level-2 units (78 participants) and predictors of interest (9) , maximum likelihood estimation was used to estimate fixed effects for the two models above (Snijders, 2012). Random intercepts for each of the models were estimated using an autoregressive covariance structure because the outcomes of interest, discrepancies between actigraphy and sleep diary SOL and TST, were measured at several time points. This covariance structure assumes that adjacent time points are more highly correlated than time points that are further apart, reflecting the fact that successive nights of sleep diary and actigraphy sleep data were collected (Hayes, 2006; Snijders, 2012). The following predictors were grand-mean centered to aid with interpretation: age, PSQI, GDS-SF, Craft Story 21 Recall, Immediate, and Craft Story 21 Recall, Delayed (Hayes, 2006). Variables for each set of analyses were entered in the following order: 1) Intercept only as a point of comparison (e.g., null model), 2) Age, gender, days since completing questionnaires and testing, 3) PSQI, 4) GDS-SF, 5) Craft Story 21

Recall, Immediate, 6) Craft Story 21 Recall, Delayed, 7) Age, PSQI, and the interaction between age and the PSQI, and 8) Age, GDS-SF, and the interaction between age and the GDS-SF. Non-significant covariates were removed before adding additional variables into the model to decrease variance (e.g., model overfitting) and as a matter of parsimony.

Results

Figure 2 (pg. 60) provides information related to participant recruitment and study completion. Seventy-eight participants provided a minimum of three days of actigraphy and sleep diary data for the current study (mean number of nights of data provided = 6.88, SD= 0.46; range 4 – 7 days). Only participants who provided both actigraphy and sleep diary data were included in the current study. A majority of participants were white (96%), non-Hispanic (99%), and female (69%) with an average age of 74.06 years (SD = 6.65; range 60 - 89 years). The median level of education for the sample was 16 years (Table 1). On average, participants reported taking 16.27 (19.67) minutes to fall asleep and spending 419.73 (71.13) minutes asleep. Mean actigraphy SOL was 3.79 (2.80) minutes and mean actigraphy TST was 400.76 (63.84) minutes. The average absolute difference between self-reported and actigraphy estimated SOL was 13.73 (18.76) minutes and the average absolute difference between self-reported and actigraphy estimated TST was 48.74 (34.13) minutes (Table 2). Overall, our sample was cognitively intact, and reported good sleep quality and a low number of depressive symptoms (Table 3). Because only one person in our sample met criteria for an anxiety disorder (Table 3), we were unable to test how meeting criteria for an anxiety diagnosis is related to the discrepancy between self-reported and actigraphy measured sleep.

Aim 1: Is there a difference between actigraphy and sleep diary data?

On average, there were statistically significant differences between self-reported and actigraphy measured SOL and TST. Self-reported SOL was significantly greater than actigraphy measured SOL (z= 6.95, p <.*001*). Self-reported TST was greater than actigraphy measured TST (z= 2.51, p= .014). These results indicate that, on average, participants perceived taking longer to fall asleep and sleeping more than what was indicated using an objective measure of their sleep.

Aims 2 and 3: How are individual characteristics related to the discrepancy between actigraphy and sleep diary SOL and TST? What is the conditional relationship between age and the discrepancy between actigraphy and sleep diary estimates of sleep?

Discrepancy between actigraphy and sleep diary SOL. Parameter estimates for the eight models examining the relationship between individual characteristics (i.e., age, gender, days since testing, sleep quality, depression, immediate and delayed memory, the interaction between age and sleep quality, and the interaction between age and depression) and the absolute difference between self-reported and actigraphy estimated SOL are in Table 4. The discrepancy between self-reported and actigraphy estimated SOL, on average, differs between participants (Model 1, $\hat{\gamma}_{00}$ = 12.14, SE = 1.49, p < .01). That is, from Model 1, the interclass correlation (ICC), which estimates the degree of nonindependence in the discrepancy between actigraphy and sleep diary SOL across days, was 0.353. This indicated that 35.3% of the total variance in the discrepancy between actigraphy and sleep diary SOL is accounted for by differences between participants' average SOL discrepancies. Each participant's daily actigraphy and sleep diary SOL discrepancy is more similar, on average, to their own than to other participants' average discrepancy (e.g., the discrepancy between actigraphy and self-reported SOL depends on the participant because the discrepancy varies between participants). Therefore, level-1 units (days

and the daily discrepancy between self-reported and actigraphy estimated TST) were not statistically independent and using multilevel modeling to analyze this data was appropriate.

Sleep quality significantly predicted the discrepancy such that participants who reported worse sleep quality had a greater discrepancy between their sleep diary and actigraphy estimated SOL (Model 3, $\hat{\gamma}_{04}$= 1.69, SE = 0.42, $p < .01$). Sleep quality was a significant predictor even when depression and immediate and delayed memory were included in the model (Models 4-6). To determine how much of the variance in the discrepancy between self-reported and actigraphy estimated SOL could be attributed to sleep quality (and was not accounted for by differences between participants), we compared the residual variances ($\hat{\sigma}^2$) between Models 1 and 3. This yields a pseudo-R^2 value that can be interpreted similarly to R^2 values derived from ordinary least squares regression analyses (Hayes, 2006). The variance explained by sleep quality was 0.00047 (.047%), after removing the variance accounted for by individual differences in how much self-reported and actigraphy estimated SOLs differed. Age, gender, the number of days between testing and participation in the study, depression, and immediate and delayed recall did not significantly predict the discrepancy between sleep diary and actigraphy estimated SOL (Models 2, 4-6).

The third aim of this study was to determine if there was a significant interaction between age and sleep quality in predicting the discrepancy between self-reported and actigraphy estimated SOL (Model 7). Sleep quality significantly predict the discrepancy, with worse sleep quality predicting greater incongruence between actigraphy estimated and self-reported SOL ($\hat{\gamma}_{04}$ = 1.72, SE = 0.42, $p < .01$). However, age and the interaction between age and sleep quality did not significantly predict the discrepancy. Although we did not find a significant main effect for age and depression, we explored the interaction of age and depression in predicting the

discrepancy between self-reported and actigraphy estimated SOL (Model 8). Age and the interaction between age and depression did not significantly predict the discrepancy between self-reported and actigraphy estimated SOL.

Discrepancy between actigraphy and sleep diary TST. Parameter estimates for the eight models examining the relationship between individual characteristics (i.e., age, gender, days since testing was completed, sleep quality, depression, immediate and delayed memory, the interaction between age and sleep quality, and the interaction between age and depression) and the absolute difference between self-reported and actigraphy estimated TST are in Table 5. The discrepancy between self-reported and actigraphy estimated TST, on average, differed between participants (Model 1, $\hat{\gamma}_{00}$ = 59.00, SE = 3.33, $p < .01$). From Model 1, the interclass correlation (ICC) was 0.214. This indicated that 21.4% of the total variance in the discrepancy between actigraphy and sleep diary TST is accounted for by differences between participants' average TST discrepancies. That is, each participant's daily actigraphy and sleep diary TST discrepancy was more similar, on average, to their own than to other participants' average discrepancy (e.g., the discrepancy between actigraphy and self-reported TST depends on the participant because the discrepancy varies between participants). Therefore, level-1 units (days and the daily discrepancy between self-reported and actigraphy estimated TST) were not statistically independent and using multilevel modeling to analyze this data was appropriate.

Age, gender, the number of days between testing and participation in the study, sleep quality, depression, and immediate and delayed recall did not significantly predict the discrepancy between sleep diary and actigraphy estimated TST (Models 2-6, $p > .01$). The third aim of this study was to determine if there was a significant interaction between age and sleep quality in predicting the discrepancy between self-reported and actigraphy estimated TST

(Model 7). Age, sleep quality, and the interaction between age and sleep quality did not significantly predict the discrepancy. There was no significant main effect for age and depression, however we explored the interaction of age and depression in predicting the discrepancy between self-reported and actigraphy estimated SOL (Model 8). Age and the interaction between age and depression did not significantly predict the discrepancy between self-reported and actigraphy estimated TST.

Discussion

Older adults are a growing segment of the population and researchers have focused efforts on understanding and anticipating the health concerns of this population. Because a majority of older adults experience disturbed sleep, researchers and clinicians have focused their efforts on understanding age-related changes in sleep in this population. Researchers and clinicians have relied heavily on two sleep measurement tools to understand these sleep patterns, actigraphy and self-report (e.g., sleep diaries). In using these tools, many studies have determined that there is a discrepancy between self-reported and actigraphy estimated sleep. It may be assumed that the discrepancy between actigraphy and sleep diaries is not important or clinically meaningful. However, research does not support this assumption. Studies have found that this discrepancy is not an artifact and is impacted by individual characteristics. It is important to study how these individual characteristics in older adults interact and influence the relationship between actigraphy and sleep diary data because it impacts sleep data interpretation, how sleep disturbance is conceptualized and treated in older adults, and older adults' treatment seeking behaviors.

The primary objective of the current study was to explore the difference between actigraphy and sleep diary estimates of sleep in older adults. Aim 1 was to determine the degree

of congruency or differences between actigraphy and diary estimates of time spent trying to fall asleep and total time spent asleep. We hypothesized that on average, participants would self-report spending more time awake and less time asleep compared to actigraphy estimates of their sleep. Aim 2 was to determine how individual differences in sleep quality, depressive and anxiety symptoms, and memory would be associated with the difference between actigraphy and sleep diary estimates of sleep. We hypothesized that having more disrupted sleep, worse mood, meeting criteria for an anxiety diagnosis, and more impaired memory would be related to a greater incongruency between actigraphy and sleep diary data. In Aim 3, we explored whether the effect of sleep disturbance, depression, or anxiety on the discrepancy between the two measures was dependent on age. There was not enough literature to guide a hypothesis on this exploratory aim.

Our results demonstrated that participants perceived taking longer to fall asleep and sleeping more than what was indicated from an objective measure of their sleep. Actigraphy estimated SOL and TST were both greater than self-reported SOL and TST. We found that worse sleep quality predicted a greater incongruence between the two measures of SOL. Sleep quality did not predict the difference between self-reported and actigraphy measured TST. We did not find that mood, memory, the interaction between age and mood, and age and memory significantly predicted the difference between self-reported and actigraphy measured SOL and TST. We were unable to test our hypothesis that worse anxiety would be related to a greater incongruency between the measures because only one person in our sample met criteria for an anxiety diagnosis.

Difference Between Self-Reported and Actigraphy Estimated Sleep

Our results replicated the findings of previous research reporting a difference between self-reported and objectively measured SOL and TST in older adults. This suggests that the discrepancy between self-reported and actigraphy measured sleep is a phenomenon that is commonly observed in older adults. More specifically, aligned with previous research, participants self-reported SOL was greater than actigraphy estimated SOL (Harvey & Tang, 2012; Rezaie, Fobian, McCall, & Khazaie, 2018). Our finding that participants' self-reported TST was greater than their actigraphy estimated TST was similar to that of McCrae et al. (2005), who found that in their community dwelling sample of older adults, self-reported TST was on average greater than actigraphy estimated TST. There is some variability in the literature regarding the direction of the TST discrepancy. For example, other studies have found that self-reported TST is often less than actigraphy estimated TST in older adults (Harvey & Tang, 2012; Kay et al., 2015; Manconi et al., 2010). Differences in sample characteristics may explain why we and McCrae et al. (2005) found that self-reported TST is greater than actigraphy estimated TST. Kay et al. (2015) and Manconi et al. (2010) included older adults that had specific complaints about disturbed sleep, whereas our sample of older adults were not recruited based upon explicit sleep concerns.

These results suggest that researchers and clinicians need to think carefully about how they choose to measure sleep, whether it is through self-report, actigraphy, or both. Given the difference between self-report and actigraphy and that the direction of the difference may vary depending on sample characteristics (e.g., self-reported TST was greater than actigraphy TST), it would be ideal to use multiple tools to measure sleep. By concurrently collecting objective and subjective sleep data, researchers and clinicians will have two sets of sleep data that they can analyze. They can also examine discrepancies between the two to determine if the characteristics

of the participants and patients biased their data in any way. This is not to say that researchers should "cherry pick" their data post-hoc when collecting both sets of data (e.g., choosing the set of data that fits with their hypotheses when publishing findings). Rather, they should be looking at their data to determine if any discrepancies exist and if the discrepancies can be explained by their methodology or by participant characteristics. We acknowledge that using multiple methods to measure sleep may not be feasible given lack of resources to purchase and maintain actigraphy monitors and software and the feasibility of using both tools with older adults with multiple comorbidities (e.g., dementia, chronic difficulty with physical movement, inability to write), which could impact adherence (e.g., willingness to fill out sleep diaries or wear actigraphy monitors for multiple days). Whether one measure or multiple are used is used to characterize sleep in older adults, it is important that researchers and clinicians consider if the sleep measurement tool they have selected 1) reflects the older adult's perceived sleep experience and 2) is influenced by patient in such a way that results are biased.

Knowing that there is a discrepancy between self-reported and actigraphy estimated sleep may also help researchers and clinicians be mindful and critical of sleep data generated from these tools. This is especially important when considering insomnia, a sleep disorder that is primarily diagnosed through self-report. In our sample, many older adults reported sleeping longer than what was demonstrated through actigraphy data. It could be that these older adults are experiencing symptoms of insomnia (i.e., difficulty initiating and maintaining undisrupted sleep) and did not report them. While they are reporting getting enough sleep at night, actigraphy estimated TST may be lower because the actigraphy monitors capture nighttime awakenings and sleep disruptions that the older adults do not perceive. Older adults may not perceive these awakenings and sleep disruptions because they are brief. They may believe that their sleep is

good when it is actually fragmented or they may not know why they wake up feeling unrefreshed after what they perceive to be a long night of sleep. Therefore, instead of relying solely on self-reported difficulty falling and staying asleep, inquiries related to physical and psychological well-being and daytime dysfunction may be helpful in determining if the individual is experiencing symptoms of insomnia.

Keeping in mind that self-report and actigraphy can differ and that each tool can be biased will also help researchers and clinicians with developing treatments for disrupted sleep. Researchers and clinicians may have to decide if they are interested in improving subjective or objective sleep or perhaps even closing the gap between subjective and objective sleep measurement tools. Knowledge of the discrepancy is also helpful when doing planning and implementing treatment for sleep disturbance in older adults. Clinicians can use this knowledge to educate patients as to why they use multiple methods to measure sleep or why they choose one tool over another. If patients are reporting not sleeping at all or going to bed or waking up at irregular times, clinicians may have difficulty implementing components of Cognitive Behavioral Therapy for Insomnia such as sleep restriction. Knowing that the self-reported values may not be congruent with objective measures would give clinicians the freedom to not solely use patients' self-reported sleep when determining new bed and wake times. Instead, clinicians could use actigraphy in conjunction with sleep diaries and work with the patient to determine the safest sleep restriction schedule.

It is important to note that the differences we observed between self-reported and actigraphy estimated SOL and TST were *on average*. That is, we compared individuals' average self-reported SOL and TST to their average actigraphy estimated SOL and TST (i.e., self-reported and actigraphy estimated SOL and TST was collapsed across all days per individual).

The multilevel modeling analyses we conducted suggested that there was variation in the degree to which self-reported sleep differs from actigraphy estimated sleep. This suggests that future research should consider examining the variability of the discrepancy across time or across participants instead of looking at the average discrepancy. Modeling the pattern of the discrepancy between self-reported and actigraphy estimated sleep would shed light on the consistency of the discrepancy and help pinpoint time points when the discrepancy may be greater (i.e., weekends versus weekdays). Additionally, understanding the pattern of the discrepancy would be helpful information for researchers and clinicians to know as it may influence how much time they monitor an older adult's sleep.

Relationship Between Individual Characteristics and the Discrepancy between Self-Reported and Actigraphy Estimated Sleep

Through our use of multi-level modeling, we found that the discrepancy between actigraphy and self-reported SOL and TST varied from participant to participant. This indicated that each participant had their own "pattern" of discrepancy (heterogeneity of differences between measures across time). This suggests that when researchers and clinicians measure sleep using multiple methods across multiple time points in older adults, they should analyze their data in such a way that allows for them to see variability in sleep across people and time. This method would allow them to capture sleep variability and patterns in their sample, which cannot be seen when aggregating sleep data across time (e.g., using means). Doing so also reflects the reality that sleep is heterogenous in older adults.

Our data demonstrated that poor sleep quality was related to a greater incongruence between self-reported SOL and actigraphy estimated SOL in older adults. This relationship was consistent with other studies that have found a relationship between disturbed sleep and

discrepancy between the two measures (Brooks et al., 1993; Edinger & Krystal, 2003; Harvey & Tang, 2012; Kay et al., 2015; Rezaie et al., 2018; N. K. Tang & A. G. Harvey, 2004; Tang & Harvey, 2006). It is important to emphasize that we explored how sleep quality was related to the degree of incongruency between self-reported and actigraphy estimated SOL and did not look at how sleep quality was related to both the degree and direction of the difference. Nonetheless, our result provides further support for the relationship between sleep quality and the discrepancy between self-reported and actigraphy estimated SOL. It also suggested that researchers and clinicians continue considering how poor sleep quality influences objective and subjective measures of SOL in older adults.

Although sleep quality was a significant predictor, it is important to note that it explains a very small proportion of the variance in self-reported and actigraphy SOL discrepancy (.047%). Overall sleep quality had a small influence on the daily discrepancy between self-reported and actigraphy estimated SOL. Previous research examining the relationship between sleep quality and the discrepancy has focused on looking at overall sleep quality and average discrepancy and few have reported the effect size of sleep quality. Because we used daily discrepancy values as our outcome, it is possible that overall sleep quality would have a greater influence on daily differences between sleep diary and actigraphy data. Researchers should consider measuring daily sleep quality in addition to overall sleep quality and exploring differences in effect size with predicting daily sleep measurement incongruency.

Sleep quality was the only significant predictor of the difference between self-reported and actigraphy estimated SOL. Previous research has found that mood and cognition influence the discrepancy between self-reported and actigraphy estimated SOL. Differences in how we measured mood, a relatively low number of depressive and anxious symptoms endorsed, and a

focus specifically on memory, may explain why we did not replicate these results and did not find a significant interaction between age and mood and age and memory. Previous studies had participants rate their mood in the morning prior to reporting on their sleep and used measures of global cognitive functioning. In contrast, we used a measure of overall depressive symptoms and a specific measure of memory. Our measures of depressive symptoms (Geriatric Depression Scale-Short Form) and memory (Craft Story 21 Recall- Immediate and Delayed) may not have been sensitive enough to detect difficulty with mood or memory impairment in our sample, especially because participants were relatively healthy older adults. Finally, much like sleep quality, it may be that researchers and clinicians need to consider how overall and daily mood impacts self-reported and actigraphy estimated SOL.

Notably, sleep quality, mood, and memory (and the interaction between age and mood and age and memory) were not significant predictors of the difference between self-reported and actigraphy measured TST. This is surprising given that previous research has demonstrated that sleep quality, mood, and memory are related to the discrepancy between the two measures. However, as discussed above, we measured overall instead of daily mood and used a measure of memory instead of global cognitive functioning, which may explain why we did not replicate previous findings. Additionally, our sample was comprised of older adults without significant memory deficits. Therefore, our findings may only be generalizable to older adults with intact memory function. Our results suggest that more research needs to be done in investigating variables that contribute to the discrepancy between self-reported and actigraphy TST in older adults and replicating other studies. Continuing to investigate predictors of the discrepancy and replicating other research would shed light on the nature of the relationship between individual

characteristics and the differences between self-reported and actigraphy measured TST (e.g., if it varies depending on how predictors are measured, composition of sample etc.).

Limitations

Although the current study replicated previous research, demonstrating that a discrepancy between self-reported and actigraphy estimated sleep is common in older adults and that it is influenced by sleep quality, it is not without limitations. We addressed a few limitations when discussing the results of the current study, such as our inability to measure sleep quality and mood daily. Other limitations included the generalizability of our findings. Given that our sample was relatively healthy and homogenous (e.g., highly educated, White, and non-Hispanic), the generalizability of our results is limited. The "healthy" status of our sample meant that many individuals did not report symptoms of poor sleep quality, depression, or anxiety. This was especially true when we assessed for anxiety in our sample. Only one individual met criteria for an anxiety disorder, which meant that we were unable to test our hypothesis that anxiety contributed to the discrepancy between self-reported and actigraphy estimated sleep. Previous research looked at symptoms of anxiety, however, this type of data was not available for the current study. Rather than focusing on meeting criteria for an anxiety disorder, assessing for anxious symptomatology may yield a greater range of responses from older adults.

Relatedly, we did not have the ability to assess other variables relevant to older adults that are known to influence the discrepancy between self-reported and actigraphy estimated sleep. These variables include pain, physical disability, and pre-sleep arousal (Harvey & Tang, 2012; Landis et al., 2003; Lunde et al., 2010; Martin & Hakim, 2011; Okifuji & Hare, 2011). Participants in the current study could have been experiencing symptoms of pain and pre-sleep arousal, which influenced their self-reported sleep. If they had difficulty with physical

movement, their actigraphy estimates of sleep would have been skewed given that actigraphy measures sleep through the presence and absence of movement.

Future Directions

The current study demonstrated the importance of continuing to consider and measure individual characteristics when assessing sleep in older adults. It also demonstrated that clinicians and researchers must carefully think about what tool they want to use to measure sleep in their population of interest. They also must think critically about how the sleep data generated by these tools may be influenced by individual factors such as sleep quality. Future studies should investigate the pattern of the discrepancy between self-reported and actigraphy measured sleep. Does the discrepancy attenuate throughout the monitoring period and/or does it differ depending on the day of the week? Answering these questions would shed more light on the discrepancy phenomena and give insight as to other factors that may impact it. Further understanding methodological factors that impact the discrepancy (e.g., length of monitoring period, inclusion of weekends versus weekdays) would allow researchers and clinicians to understand how their research and clinical protocols may be influencing the sleep data they collect.

More work examining the influence of psychological and physiological functioning and processes would also be beneficial to the field of older adult sleep research. We previously discussed that future work should include daily measures of psychological and physiological functioning. A majority of the research on the discrepancy between objective and subjective measures of sleep has focused on the role of global cognitive functioning. Future research may expand this topic by specifically focusing on the role memory and perhaps examining if immediate and delayed recall have different relationships to the discrepancy between sleep

measures. There is a paucity of research that has examined the relationship among self-reported and actigraphy measured sleep and physical disability beyond pain. Given that actigraphy measures sleep based upon the absence and presence of movement, future work could include older adult populations with limited mobility, physical disability, or movement disorders (e.g., Parkinson's disease). There is also a lack of research regarding the influence of polypharmacy on self-reported and actigraphy measured sleep in older adults. Future research may consider including polypharmacy as a variable of interest because it can indicate that a participant is experiencing multiple health concerns. More data in this field furthers our knowledge of older adult sleep patterns. Continuing to understand all the factors that impact how sleep is perceived and how it is objectively measured allows us to also further our understanding of how to best assess and treat sleep disturbance in this population. More data would also allow researchers and clinicians to see a wider range of self-reported and actigraphy measured sleep patterns in older adults.

Finally, it would be appropriate for researchers to continue exploring the meaning of the discrepancy between actigraphy and sleep diary estimates of sleep. Research has demonstrated that the discrepancy between actigraphy and sleep diaries is common and is observed in those with and without insomnia. The discrepancy is greater amongst those that report of disturbed sleep than amongst those that do not. Research has also found that treating sleep disturbance reduces this discrepancy. Clinicians may consider using a reduced discrepancy between actigraphy and sleep diary estimates of sleep as a clinically meaningful outcome. This leads to another question of determining a "cut-off" for the discrepancy. For example, what degree of incongruence between self-reported and actigraphy estimated sleep is acceptable and at what point is the discrepancy clinically significant? Also, because we found that self-reported TST

was greater than actigraphy estimated, future studies should explore what causes older adults to perceive that they are sleeping more than what is observed through objective measures. More work should be completed to determine if the lack of a discrepancy between measures is clinically significant. Future work in understanding the discrepancy between actigraphy and sleep diaries should also investigate individuals who have improved sleep, but no reduction in discrepancy between the two measures. This would allow for researchers and clinicians to understand the complexity and perhaps heterogeneous meaning of the discrepancy between actigraphy and sleep diary estimates of sleep.

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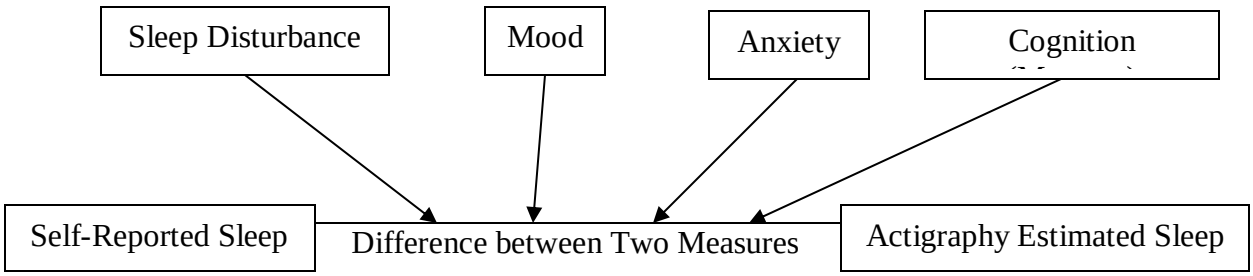

Figure 1. Factors that contribute to the discrepancy between actigraphy and sleep diary data.

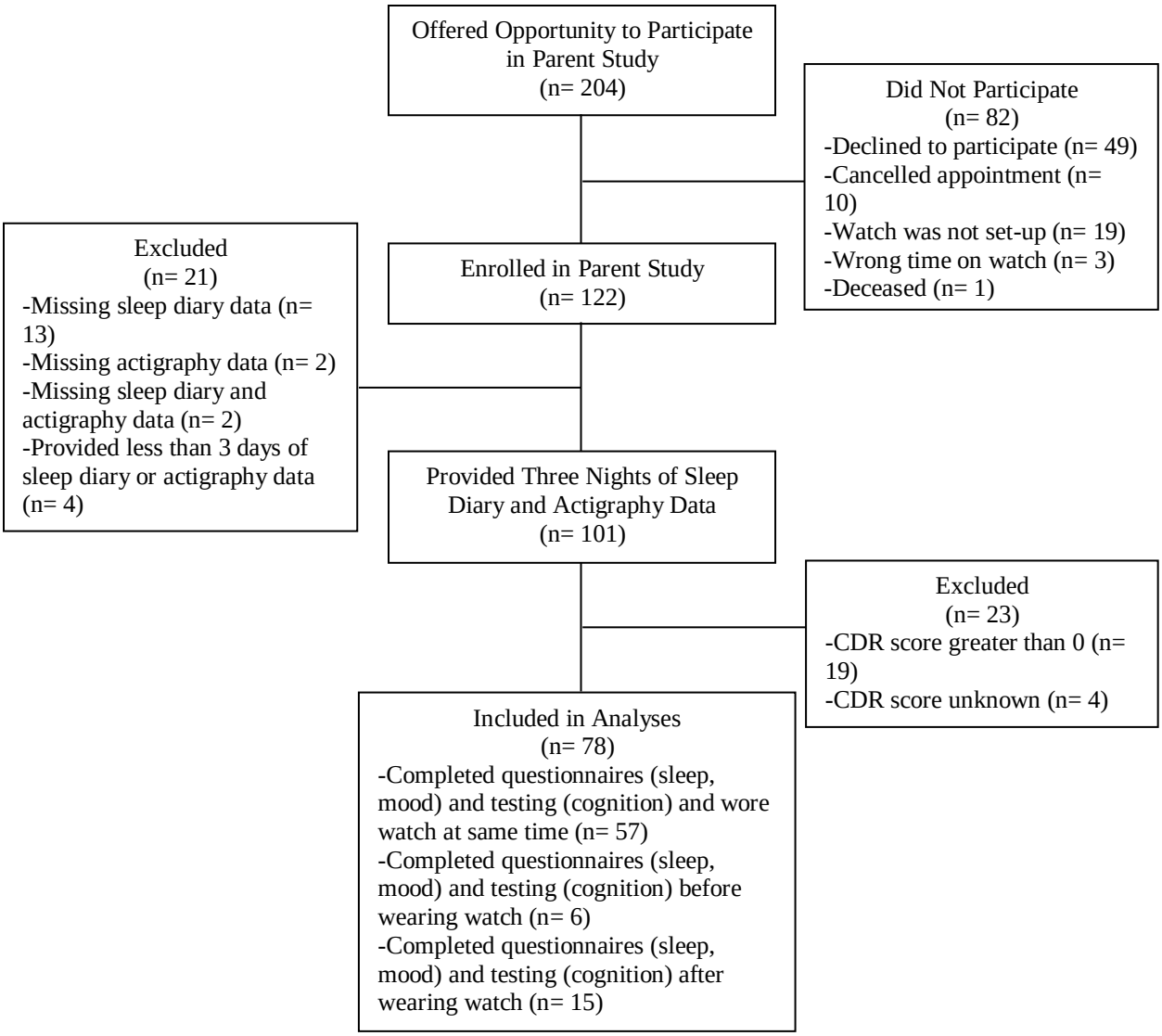

Figure 2. Recruitment consort diagram

Table 1

Participant Demographic Information

Demographic Variable	Mean (SD)	Median	Minimum	Maximum
Age (Years, SD)	74.06 (6.67)	73.50	60	89
Days Since Completing Questionnaires and Testing	88.28 (151.50)	0	0	414
Race (n, %)				
White	75 (96%)	—	—	—
African American	2 (3%)	—	—	—
Asian	1 (1%)	—	—	—
Ethnicity (n, %)				
Non-Hispanic	77 (99%)	—	—	—
Hispanic	1 (1%)	—	—	—
Gender (n, %)				
Female	54 (69.2%)	—	—	—
Male	24 (30.8%)	—	—	—
Years of Education	16.26 (3.03)	16	12	26

Table 2

Participant Sleep Characteristics

Sleep Characteristic	Mean minutes (SD)	Median	Minimum	Maximum
Self-Report				
SOL	16.27 (19.67)	10	0	120
TST	419.73 (71.13)	420	225	550
Actigraphy				
SOL	3.79 (2.80)	4	0	11
TST	400.76 (63.84)	400	262	519
Absolute Difference between Self-Reported and Actigraphy Estimated SOL	13.73 (18.76)	7	0	115
Absolute Difference between Self-Reported and Actigraphy Estimated TST	48.74 (34.13)	48.50	0	130

Note. SOL= Sleep Onset Latency; TST= Total Sleep Time.

Table 3

Predictors

Study Measure	Mean (SD)	Median	Minimum	Maximum
PSQI Total Score (mean, SD)	4.49 (3.28)	4	0	14
**Higher scores denote greater sleep disruption*				
Craft Story 21 Recall				
**Higher scores denote more items recalled*				
Immediate	24.45 (6.62)	25	8	38
Delayed	21.10 (6.87)	20.50	6	33
GDS-SF Total Score	.97 (1.36)	.50	0	6
**Higher scores denote greater symptoms of depression*				
Met Criteria for Anxiety Diagnosis (n, %)	1 (1%)	—	—	—

Note. PSQI= Pittsburgh Sleep Quality Index; GDS-SF= Geriatric Depression Scale- Short Form.

Table 4

Predictors of the difference between self-reported and actigraph estimated sleep onset latency.

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Fixed Components									
Intercept	$\hat{\gamma}_{00}$	12.14*	10.60	12.12*	12.11*	12.13*	12.13*	12.20*	11.94*
Age	$\hat{\gamma}_{01}$		-0.11					-.002	-.03
Gender	$\hat{\gamma}_{02}$		1.09						
DST	$\hat{\gamma}_{03}$		0.01						
PSQI	$\hat{\gamma}_{04}$			1.69*	1.72*	1.73*	1.73*	1.72*	1.72*
GDS-SF	$\hat{\gamma}_{05}$				-1.04				-1.21
Immediate Recall	$\hat{\gamma}_{06}$					0.22			
Delayed Recall	$\hat{\gamma}_{07}$						.12		
Age x PSQI	$\hat{\gamma}_{08}$							0.03	
Age x GDS-SF	$\hat{\gamma}_{09}$								-.09
Variance of Random Components									
	$\hat{\tau}_{00}$	139.18*	136.99*	109.59*	107.68*	107.37*	108.92*	109.08*	106.98*
	$\hat{\sigma}^2$	231.74	231.74	231.63	231.60	231.69	231.65	231.66	231.58
	ρ	-.022	-.022	-.021	-.021	-.020	-.020	-.020	-.021
Deviance (-2LL)		4502.04	4501.04	4487.06	4485.97	4485.89	4486.71	4486.83	4485.58

**p<.001*

Note. Unstandardized coefficients are reported. DST= Days since testing; PSQI= Pittsburgh Sleep Quality Index total score; GDS-SF= Geriatric Depression Scale-Short Form total score; Immediate Recall= Craft Story 21 Recall, Immediate score; Delayed recall= Craft Story 21 Recall, Delayed score; Age X PSQI= Age and PSQI interaction term; Age X GDS-SF= Age and GDS-SF interaction term; Age, PSQI, GDS-SF, Craft Immediate, and Craft Delated were grand mean centered.

Table 5

Predictors of the difference between self-reported and actigraph estimated total sleep time.

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Fixed Components									
Intercept	$\hat{\gamma}_{00}$	59.00*	66.64*	59.00*	58.97*	59.00*	59.01*	59.42*	59.36*
Age	$\hat{\gamma}_{01}$		0.75					.86	0.72
Gender	$\hat{\gamma}_{02}$		-7.47						
DST	$\hat{\gamma}_{03}$		-.017						
PSQI	$\hat{\gamma}_{04}$			0.61				1.00	
GDS-SF	$\hat{\gamma}_{05}$				-2.28				-1.23
Immediate Recall	$\hat{\gamma}_{06}$					-0.10			
Delayed Recall	$\hat{\gamma}_{07}$						0.20		
Age x PSQI	$\hat{\gamma}_{08}$							0.17	
Age x GDS-SF	$\hat{\gamma}_{09}$								0.21
Variance of Random Components									
	$\hat{\tau}_{00}$	529.08*	483.49*	526.54*	519.86*	528.91*	526.14*	480.63*	490.53*
	$\hat{\sigma}^2$	1943.80	1944.42	1942.81	1944.18	1943.59	1944.63	1944.86	1945.39
	ρ	.09	.09	.09	.09	.09	.09	.09	.09
Deviance (-2LL)		5566.51	5562.42	5566.16	5565.65	5566.47	5566.35	5562.08	5563.13

**p<.001*

Note. Unstandardized coefficients are reported. DST= Days since testing; PSQI= Pittsburgh Sleep Quality Index total score; GDS-SF= Geriatric Depression Scale-Short Form total score; Immediate Recall= Craft Story 21 Recall, Immediate score; Delayed recall= Craft Story 21 Recall, Delayed score; Age X PSQI= Age and PSQI interaction term; Age X GDS-SF= Age and GDS-SF interaction term; Age, PSQI, GDS-SF, Craft Immediate, and Craft Delated were grand mean centered.