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THE RELATIONSHIP BETWEEN OBJECTIVE AND SUBJECTIVE SLEEP QUALITY IN PEDIATRIC OBSTRUCTIVE SLEEP APNEA

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ABSTRACT

Background: There is a paucity of research that specifically addresses sleep quality impairment in children with obstructive sleep apnea (OSA). This study will describe objective and subjective sleep quality in children with OSA and explore the relationship between objective and subjective measures of sleep quality.

Theoretical Framework: Increased frequency of respiratory-event related arousals and fragmentation of sleep in OSA disrupt normal sleep architecture, such that the homeostatic process of sleep is not sufficient and sleep quality is poor, as supported by the Two-Process Model of Sleep Regulation.

Methods: A post-hoc, descriptive analysis of data from a parent study of children with OSA (n=28). Inclusion criteria: (1) male or female children aged 5-18 years, and (2) OSA diagnosis (apnea hypopnea index [AHI] ≥ 1 event/hr). Exclusion criteria: neuromuscular disease or chronic respiratory failure. Data was extracted from source documents (EMR and polysomnogram [PSG] acquisition system database). Data accrual was complete if a diagnostic PSG report was available. Objective sleep quality variables from PSG include: AHI, O2 saturation nadir, total sleep time, arousal index, respiratory effort related arousal index, wake after sleep onset, sleep efficiency, and sleep stage distribution (N1-N3; REM); subjective sleep quality measured by a single self-report item was assessed the morning after PSG. Descriptive statistics, graphical examination of variable distribution, and correlational procedures for objective and subjective sleep quality relationship are reported.

Results: The sample of children and adolescents (mean age [yrs], 12.03± 3.43) with complete data for the analysis (n=28) included primarily males (61%) with severe OSA (mean AHI, 20.95 events/hour ± 25.53). The sample demonstrated objective disrupted sleep, as measured by PSG.
In contrast, subjects rated their sleep quality primarily as good or average. No relationship existed between objective sleep quality, defined by respiratory event related arousals (RERAs), and self-reported subjective sleep quality though a possible increasing monotonic trend was identified via scatter plot. An exploratory correlational analysis between self-reported subjective sleep quality and objective sleep quality, measured as sleep efficiency by PSG revealed a significant increasing monotonic relationship (Spearman’s r = 0.69, p = 0.00), also verified by scatter plot.

**Conclusions & Implication:** Overall sleep quality assessment by a simplistic survey item is not sensitive or specific to OSA in children. Screening for OSA in children cannot be reliably or accurately assessed by simplistic self-report of sleep quality. Rather, OSA screening should include use of validated OSA screening tools, such as STOP-BANG for children tool, to identify possible OSA; with a positive screening, follow up by PSG is necessary.
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Chapter 1

Introduction

Obstructive sleep apnea (OSA) is the most prevalent sleep-related breathing disorder (AASM, 2005). It is characterized by apneas and hypopneas, which are defined, respectively, as complete and partial airway obstructions that lead to the cessation of breathing (Sawyer & Weaver, 2011). These respiratory events are typically terminated by cortical arousals during sleep resulting in sleep fragmentation. In particular, OSA is associated with the suppression of slow wave sleep (SWS) and rapid eye movement (REM) sleep (Sawyer & Weaver, 2011). As mentioned by the Centers for Disease Control and Prevention (CDC), those with sleep apnea may experience excessive daytime sleepiness, as their sleep is frequently interrupted by respiratory-related arousals and thereby sleep is not restorative (Centers for Disease Control and Prevention [CDC], 2013). This disruption of the natural sleep architecture equates with poor sleep quality.

Obstructive Sleep Apnea in Children

In the pediatric population, OSA diagnoses are estimated to be between 1 and 3 percent (Walter et al., 2011). The prevalence, estimated by Walter et al. (2011), as a 2.5:1 ratio, cases to controls suggests OSA in children is a significant public health problem. It is therefore imperative to reduce/eliminate modifiable OSA risk factors, such as obesity, in children (Walter et al., 2011). This population is at a critical period of brain development. OSA with recurrent
hypoxia has detrimental effects on brain function. Therefore, the impact of OSA may be more severe and result in both immediate and long-term negative health and function consequences than in adults (Gozal, 2008). One of the most important consequences of OSA in children are psychobehavioral comorbidities (Gozal, 2008). The majority of children with OSA exhibit neurocognitive and behavioral problems, such as impaired concentration and mood changes (Walter et al., 2011). Additional effects of OSA include impaired glucose tolerance, insulin resistance, and increased heart rate (AASM, 2005). Furthermore, cardiovascular disease risks are heightened, as well as a predisposition for type 2 diabetes, in children diagnosed with OSA (Muggiano et al., 2014). Collectively, OSA is a deleterious health problem in children.

**Clinical presentation and diagnosis.** Upon clinical examination, reports of frequent snoring, labored breathing during sleep, headaches on awakening, attention-deficit/hyperactivity disorder and daytime sleepiness should raise suspicion for OSA diagnosis (Friedman, 2013). The gold standard procedure for diagnosing OSA in children is overnight polysomnography (PSG). This type of sleep study consists of electroencephalography (EEG), chin/eye/leg electromyography (EMG), electrooculography (EOG), chest and abdomen respiratory effort plethysmography, nasal airflow pressure, and pulse oximetry (Sawyer & Weaver, 2011). These polysomnography measures result in calculated indices of sleep and OSA including, the apnea hypopnea index (AHI), an index of OSA severity, and the respiratory related arousal index (RERA), an index of sleep fragmentation; these indices are important diagnostic indicators of OSA. The American Association of Pediatrics’ clinical practice guideline dictates that if a child or adolescent snores on a regular basis, clinicians should refer the patient to a sleep specialist to obtain a polysomnogram (Marcus et al., 2012). The American Academy of Sleep Medicine defines diagnosable OSA in children as an AHI of ≥1 event per hour (Muggiano et al., 2014).
Sleep fragmentation in children with OSA. Like in adults, children with untreated OSA experience repetitive nocturnal respiratory events, which are usually associated with arousals that result in sleep fragmentation (Sawyer & Weaver, 2011). The occurrence of cortical arousals, as measured during polysomnography by EEG, influences sleep architecture, or the normal progression of sleep development by stages over the course of a sleep bout (Sawyer & Weaver, 2011). Such fragmentation may cause the regression of sleep stages and increased time to onset of rapid eye movement (REM), or REM latency. Therefore, REM is reduced in children with OSA. This pattern of sleep fragmentation can be objectively measured and visualized by polysomnography and equates to poor objective sleep quality. Poor sleep quality leads to everyday functional and cognitive impairments and contributes to long-term health consequences. By measuring the cortical arousals that disrupt the architecture of sleep by EEG, an objective, quantifiable measure of sleep quality by polysomnography is entirely feasible. By examining respiratory-related arousals in children with OSA, the deleterious effects of sleep fragmentation on sleep architecture in children with OSA can also be defined. This is important because the manifestations of such poor sleep quality include significant daytime impairments (Walter et al., 2011). Ultimately, cortical arousals, both respiratory-event related and others, undermine the daytime function and cognition of children with OSA (Walter et al., 2011).

Physiological Model of Sleep Regulation

The theoretical framework of this study, the Two-Process Model of Sleep (figure 1), integrates a sleep-dependent homeostatic process and a sleep-independent circadian process to describe sleep regulation (Borb & Achermann, 1999). Together, both processes establish the near 24-hour cycle of sleep and wakefulness. The homeostatic process, referred to as Process S,
describes the need for sleep that accumulates while awake; this is often considered sleep pressure that stems from sleep debt. The circadian process, referred to as Process C, is independent of prior waking and sleep (Carskadon et al., 2004). This process regulates the tendency to sleep; that is, a greater propensity at night than during the day (Achermann et al., 1993). As the day progresses and sleep pressure (S) increases, the circadian drive to be wakeful decreases at which time sleep is achieved (Borb & Achermann, 1999). In children with OSA, the homeostatic process of sleep is impaired such that sleep debt is not completely resolved on a 24-hour period, disrupting the natural regulation of sleep (Miller, Kyle, Melehan, & Bartlett, 2014).

**Subjective and Objective Sleep Quality**

Objectively, sleep quality is determined by measurement of sleep architecture by EEG compared to established standards (AASM, 2007). This includes sleep stages (N1, N2, N3, REM). In addition the measure of respiratory-event related arousals (RERAs) is also used to quantify sleep disturbance (Yang et al., 2010). Subjective sleep quality data, however, is defined only by the individual’s perception of their experience with sleep, often assessed by questionnaire to determine subjective sleep quality. A Likert-type scale is useful in identifying an individual’s satisfaction with one’s own sleep (Gurubhagavatula, 2010).

**Significance of the Problem**

Poor sleep quality impairs daytime function (Esposito et al., 2013). Manifestations of poor sleep quality include daytime sleepiness, depression, impaired memory, impaired reaction time, and mood disorders (Yang et al., 2010). In children, impairments related to poor sleep quality are often reflected by behavioral impairments (Owens, 2009). The sequela of pediatric
OSA includes increased hyperactive behaviors, inattentiveness, and decreased memory performance when compared to healthy, non-OSA children (Gozal, 2008). There is also a significant risk for developing long-term health consequences in children with OSA. Specifically, OSA in childhood may trigger the early onset and progression of diseases that usually emerge in late adulthood (Gozal & Kheirandish-Gozal, 2008). Poor sleep quality increases the risk for metabolic disorders, such as obesity and diabetes, as well as early onset cardiovascular disease and cardiovascular mortality (Katz & D’Ambrosio, 2010). In particular, slow wave sleep (SWS) has important implications for metabolic homeostasis during the night (Carskadon & Dement, 2011). The reduction of SWS and disruption of the homeostatic process of sleep as a result of recurrent hypoxia and increased arousals seen in OSA begets insulin sensitivity and glucose tolerance changes, as well as changes in fat storage mechanisms (Katz & D’Ambrosio, 2010). There is also an acute inflammatory response to the curtailment of SWS. This inflammatory cascade pathway is hypothesized to result in early hypertension, atherosclerotic plaque development, and other cardiovascular risks (Katz & D’Ambrosio, 2010). Both OSA and poor sleep quality in children combine to heighten health risks and contribute to functional and cognitive impairments.

**Study Objective**

Sleep quality and the effect that poor quality sleep has on children may be readily overlooked by clinicians due to the lack of clinically-available, reliable data at the time of assessment. The question then follows, in children and adolescents with obstructive sleep apnea, how do OSA-related cortical arousals disrupt the normal distribution of sleep stages, such that, the disease influences impaired/poor objective sleep quality (sleep stage distribution; wake after
sleep onset; respiratory event related arousals; total arousals during sleep) and subjective sleep quality (self-reported sleep quality assessed immediately after awakening)? Using data from a retrospective single cohort study, this post-hoc analysis aims to (1) describe objective sleep quality, defined by respiratory event related arousals (RERAs), and subjective sleep quality, defined as a single item sleep quality rating on the morning after PSG questionnaire, in children and adolescents (ages 5-18 years) with obstructive sleep apnea; and (2) explore the relationship between subjective sleep quality, defined as a single item sleep quality rating on the morning after PSG questionnaire, and objective sleep quality, defined by respiratory event related arousals (RERAs), in children and adolescents (ages 5-18 years) with obstructive sleep apnea.

This study will explore the relationship between subjective sleep quality and objective sleep quality in children. If this study yields results similar to that of studies in adults, that is, a weak to moderate correlation between objective and subjective sleep quality data, the study findings will suggest that it is critical to incorporate the assessment of objective sleep quality in the pediatric clinical setting for children at risk for OSA.

**Nursing Implications**

Routine clinical screening procedures are inadequate for determining impaired sleep quality. Healthcare providers, nurses and/or others, need to be able to rapidly assess sleep quality impairments or risk for sleep quality impairments in children. Given that OSA is such a risk, rapid screening for OSA is needed in pediatric clinical settings. Furthermore, the short- and long-term effects of sleep quality impairment have significant consequences for children. Nurses need to be able to recognize OSA, realize the health and functional consequences of the disease, and refer patients appropriately. Though subjective sleep quality can be assessed in the clinical
setting, and it is appropriate to do so, nurses need to understand that an objective assessment of sleep quality in children with OSA is more accurate and specific; therefore, nurses need to proactively suggest children with risk of OSA undergo polysomnography for diagnosis and treatment. This ultimately will result in the overall reduction of OSA-related poor everyday function and morbidities in the pediatric population.

**Key Terms**

The key terms to be included in this thesis include:

*Apnea.* The complete cessation of breathing (Ishman, 2012).

*Hypopnea.* A partial cessation in breathing (Ishman, 2012).

*Polysomnograph.* A diagnostic tool used to provide an objective, quantitative evaluation of disturbances in respiratory and sleep patterns (Marcus et al., 2012). This type of sleep study is the gold standard for diagnosing sleep apnea (Sawyer & Weaver, 2011).

*Sleep architecture.* The basic structural organization of normal sleep (Colten et al., 2006).

*Sleep fragmentation.* Sleep that is sufficient in amount but is disrupted by conditions that result in frequent or prolonged arousals, typically indicative of poor sleep quality (Carskadon & Dement, 2011).

*Sleep Quality.* The degree of excellence in sleep (Ramirez et al., 2013).
Figure 1. Two Process Model of Sleep

Figure 1 (above) illustrates the interaction between the circadian (C) and homeostatic (S) sleep processes that regulate sleep. As sleep pressure (S) increases and the circadian drive to be wakeful decreases, sleep is achieved. Reprinted with permission from Copyright Clearance Center (Appendix B); original published figure from *Principles and practice of sleep medicine* (Kryger, M., Roth, T., Dement, W., 2005, p. 316).
Chapter 2

Literature Review

Obstructive sleep apnea (OSA) is the most common sleep-related breathing disorder (Sawyer & Weaver, 2011). If left untreated, OSA has serious health and functional implications. In children, OSA impacts neurocognitive and behavioral outcomes, physical development, and cardiovascular health (Katz & D’Ambrosio, 2010; Yang et al., 2010). This section will review literature on the epidemiology and clinical management of OSA in children, the OSA-related disruption of sleep quality, the various methods used to measure sleep quality, and identify the short- and long-term consequences of impaired sleep quality in children with OSA.

A literature search was performed using PubMed (Medline), the Cumulative Index to Nursing and Allied Health Literature (CINHAL), and PsycINFO (via ProQuest). These three databases were searched using the terms: sleep apnea, obstructive sleep apnea, sleep quality, sleep fragmentation, sleep architecture, cortical arousal, neurocognition, behavior, executive function, obesity, and cardiovascular risk. Articles met inclusion criteria if they were published in English between 2008 and 2015 and included children less than or equal to 18 but older than 5 years of age. Articles focused on adult populations were excluded, as were articles that did not specifically address sleep quality. Articles were reviewed for relevance and excluded first by title, then by abstract review, and lastly through full text review. The search yielded 23 articles after application of inclusion/exclusion criteria (figure 2).
Epidemiology of Obstructive Sleep Apnea

Recent general pediatric population study results suggest that the prevalence of pediatric OSA ranges from 1.2% to 5.7% (Marcus et al., 2012). In children, an apnea index (AI) of more than one or an apnea hypopnea index (AHI) of 1.5, is considered abnormal; most pediatric sleep specialists recommend treatment of any child with an AI greater than 5 (AASA, 2015). Risk factors for OSA in children include adenotonsillar hypertrophy, obesity, race, gender, prematurity, craniofacial dysmorphology, neurologic disorders, nasal/pharyngeal inflammation, socioeconomic/environmental disadvantages, and family history (Ishman, 2012). In particular, the risk of developing moderate OSA increases 12% for each 1 kg/m² of body mass index (BMI) above the normative measure of body fat based on height and weight (Katz & D’Ambrosio, 2010). With the increasing prevalence of obesity among children of all ages, the prevalence of OSA in children is likely to continue to increase (Kohler & van den Heuvel, 2008). The increased prevalence of OSA in children is likely to lead to worsened morbidity and mortality in the long term.

Short- and long-term consequences of OSA in children. In the case of OSA, daytime symptoms evolve from sleep that is adequate in amount (i.e., Total Sleep Time, TST) but fragmented or disrupted by repetitive upper airway collapse, including apneas and hypopneas, and intermittent hypoxia that collectively result in frequent or prolonged cortical or actual arousals (Owens, 2009). This repetitive cycle results in daytime impairments. In children, sleepiness, a characteristic symptom of OSA, is often displayed behaviorally (Gozal, 2008). When comparing children with OSA to healthy control children, an increase in hyperactive and inattentive behavior is observed, as is a decrease in memory performance (Gozal, 2008). Studies that have compared neuropsychological functions in children with OSA have found that the most
significant impairments occur for tasks involving reaction time, vigilance, and sustained and selective attention (Owens, 2009).

Additional consequences of OSA include increased morbidity, increased mortality, and heightened risk for other medical conditions, such as cardiovascular disease and type 2 diabetes (Sawyer & Weaver, 2011). Hypoxemia and arousals during sleep in OSA lead to sympathetic activation which results in poor sleep efficiency (Marcus et al., 2012). Furthermore, according to the Enright et al. study (2003), sleep efficiency is independently associated with elevated systolic blood pressure. A recent level IV study demonstrated a correlation between the presence/severity of OSA and indices of elevated BP (Marcus et al., 2012). Study findings also suggested the presence of cardiac strain and metabolic syndrome (Figure 3) in children who have moderate to severe OSA (Marcus et al., 2012). Early onset cardiovascular disease in children with OSA confers increase cardiovascular morbidity in adulthood. Good sleep is therefore a strong predictor of good health (Esposito et al., 2013).

**Clinical Diagnosis & Management of Obstructive Sleep Apnea in Children**

Adult and pediatric diagnostic criteria for OSA differ. Differences in the types of respiratory events that patients at different ages with OSA experience are what guide the diagnostic criteria for children and adults (Ishman, 2012). Children are more likely to experience a partial cessation in breathing (hypopneas) rather than discrete apneas, or complete breathing cessation (Ishman, 2012). Additionally, arousals in children with OSA are less common than in adults. For this reason, the American Academy of Sleep Medicine (2005) defines diagnosable OSA in children as starting at an apnea hypopnea index (AHI) of one event per hour; whereas, a mild OSA diagnosis in adults is described as having an AHI of 5-15 events per hour. Moderate-
severe OSA criteria in children is based on an AHI of > 10 events per hour in a child who is 12 or younger, compared with adult criteria of AHI > 15 events/hour (AASA 2015).

**What are the presenting symptoms of OSA?** Pediatric OSA may be initially identified by daytime manifestations of the disease. Symptoms include mouth breathing, excessive sleepiness, aggression/moodiness, and difficulty in school (Alexander & Schroeder, 2013). Furthermore, increased energy consumption associated with the increased work of breathing may result in failure to thrive in younger children (Alexander & Schroeder, 2013). Nocturnal symptoms include snoring, gasping, noisy breathing, respiratory retractions, restlessness, and neck hyperextension (Alexander & Schroeder, 2013). Snoring is the most common OSA-associated symptom. If snoring occurs more than three nights per week, clinicians should ideally request an overnight polysomnograph (Friedman, 2013). These symptoms are most obvious to the parent; therefore, parental observations are often what prompt initial evaluation.

**How is pediatric OSA diagnosed?** Polysomnography is the gold standard for diagnosing OSA (Sawyer & Weaver, 2011). A polysomnogram (PSG) for a child most commonly occurs in a sleep laboratory, where a polysomnography technologist continuously monitors the sleeping child. A PSG provides an objective, quantitative evaluation of disturbances in respiratory and sleep patterns (Marcus et al., 2012). PSG diagnostics are nearly the same in children as in adults; however, in children, capnography is added for CO2 monitoring and often only a thermistor is used for oronasal air flow rather than both thermistor and pressure transducer as in adults (Kushida et al., 2005). The outcome measures of a PSG include sleep architecture (i.e. sleep staging), sleep efficiency, respiratory-event related arousals (RERAs), spontaneous arousal index (SAI), obstructive apnea/hypopnea index (OAHI), respiratory disturbance index (RDI), and oxygen distribution (Friedman, 2013). These measures are used to establish the diagnosis and
severity of OSA (Sawyer & Weaver, 2011). In children with OSA, there is a significant correlation between disease severity and functional deficiencies related to the disease progression (Yang et al., 2010). If PSG is indicative of OSA, early intervention and treatment are recommended to prevent/minimize the onset of daytime impairments and long-term consequences of OSA.

**What is the treatment for children with OSA?** The first-line treatment of childhood OSA is adenotonsillectomy, assuming the child has adenotonsillar hypertrophy upon clinical examination (Marcus et al., 2012). Though it is an invasive surgical procedure, post-surgical PSG measures show a dramatic improvement in sleep respiratory parameters (Mitchell, 2007). In general, this one-time only procedure with relatively low morbidity is preferable to lifelong treatment with continuous positive airway pressure (CPAP) (Marcus et al., 2012). CPAP, however, is increasingly used in children who do not respond to surgery or in those for whom surgery is not recommended (Sawyer et al., 2011). CPAP is an electronic device that delivers air at positive pressure via a nasal mask, leading to mechanical stenting of the airway and improved functional residual capacity of the lungs (Marcus et al., 2012). However, the effectiveness of this treatment is often limited by suboptimal adherence (Sawyer et al., 2011). In children who are overweight, weight loss is suggested in addition to other therapy.

**Is OSA responsive to treatment in children?** Expert opinion suggests that treatment of OSA can reverse neurocognitive and behavioral deficits that manifest in children as a result of the disease (Gozal, 2008). Gozal mentions a “learning debt” that is associated with the delay of treatment (Alexander & Schroeder, 2013). For every day that treatment is delayed, cognitive deficits grow stronger and it becomes more difficult to reverse the effects that OSA has on
children (Esposito et al., 2013). Essentially, this learning debt can be mitigated; early treatment confers greater neurocognitive improvement in children (Alexander & Schroeder, 2013).

Children who receive OSA treatment at an early age show significant improvements in PSG parameters (Marcus et al., 2012). A cohort study of 619 children that was designed to examine differences in sleep architecture between children with primary snoring, mild OSA, and moderate-severe OSA, confirms that disturbed sleep architecture is reversible following treatment of OSA (Zhu et al., 2014). This includes an increased percentage of slow wave sleep (SWS) and rapid eye movement (REM) sleep; this improvement in sleep architecture equates to an overall improvement in sleep quality. Particularly, SWS preservation, but also REM sleep preservation, is essential for neurocognitive and behavioral function.

Sleep Quality in Children with Obstructive Sleep Apnea

Poor sleep quality in children with OSA is often overlooked or under-recognized by health care providers. Furthermore, there is a paucity of research that specifically addresses sleep quality impairments in children with OSA. The disruption of the natural architecture of sleep, whether it be regression or fragmentation of sleep stages, is indicative of poor sleep quality (Sawyer & Weaver, 2011). To improve sleep quality and thereby important health and functional outcomes among children with OSA, it is important that clinicians recognize OSA, refer appropriately to diagnostic testing, and address OSA treatment with children and their families.

What is sleep quality? Quality is defined as a degree of excellence (Oxford English Reference Dictionary, 2015). Sleep quality, therefore, refers to the degree of excellence in sleep. Sleep quality can be quantified and measured objectively with PSG. The objective domains of sleep quality include sleep onset latency (SOL), sleep maintenance, depth of sleep, sleep stage
progression, wake after sleep onset (WASO), total sleep time (TST), respiratory-event related arousals (RERAs) and spontaneous arousals during sleep (Yi, Shin, & Shin, 2006). Subjective sleep quality, or the individual’s perception of satisfaction with sleep can also be measured. Such subjective domains of sleep quality include satisfaction with sleep, sense of recovery with sleep, and residual sleepiness after sleep (Nishiyama et al., 2014).

**How is sleep quality disrupted in OSA?** The homeostatic process of sleep is impaired in OSA, such that sleep debt, or sleep pressure, is not completely resolved on a regular, 24-hour period (Miller et al., 2014). Sleep disorders, such as obstructive sleep apnea, have an impact on the structure and distribution of sleep stages. Respiratory events that occur with OSA are usually associated with arousals from sleep that terminate these events (Sawyer & Weaver, 2011). The increased frequency of respiratory-event related arousals and fragmentation of sleep disrupt the normal sleep architecture, such that, the homeostatic process of sleep is not sufficient and sleep quality is poor (Carskadon & Dement, 2011).

**Measures of sleep quality.** Sleep quality can be measured subjectively. A subjective measure of sleep quality is defined by how a person perceives his or her own sleep. Subjective measures of sleep quality in children include self report questionnaires for both parent/guardian and child, unless the child is seven years or older (Kadmon, Chung, & Shapiro, 2014). Subjective sleep quality is most often evaluated using the Pittsburgh Sleep Quality Index (PSQI) (Nishiyama et al., 2014). The PSQI consists of 19 items of which respondents indicate the amount of sleep they obtained and rate the extent to which various factors interfered with their sleep on a Likert-type scale (Nishiyama et al., 2014). Higher total scores indicate poorer sleep quality. Subjective sleep quality is additionally determined by sleep quality ratings on post-sleep
Sleep quality is also measured by objective measures. Objective measures include, but are not limited to, polysomnography, actigraphy, and pulse wave amplitude (PWA). A traditional PSG indicates the quality of sleep and sleep time, as well as, the amount of sleep and relative distribution of the sleep stages (Krystal & Edinger, 2008). A PSG also identifies pathological events, such as apneas, hypopneas, and arousals that indicate sleep-related breathing disorders (Sawyer & Weaver, 2011). Actigraphy measures the position and velocity of movement during sleep as a proxy for wakefulness (Krystal & Edinger, 2008). This method has a low burden to the user and typically allows data to be collected for long periods of time; however, actigraphy is not reliable in OSA as an estimate of sleep quantity or quality, as respiratory related arousals and awakenings cannot be readily differentiated in the absence of electroencephalography and respiratory measures. Also mentioned, PWA is easily obtained from a pulse oximeter. During an obstructive respiratory event, vasodilation followed by intense vasoconstriction, should increase pulse wave amplitude. This is indicative of sleep fragmentation as a result of respiratory events and arousals during sleep (Ramirez et al., 2013).

The gold standard for measuring the sleep quality in OSA is an overnight PSG (Sawyer & Weaver, 2011). This is true for OSA patients of any age. After an extensive review of the literature, numerous studies yielded consistent PSG findings in children diagnosed with OSA (Walter et al., 2011; Ramirez et al., 2013; Zhu et al., 2014; Gozal & Kheirandish-Gozal, 2008). Though PSG data is vulnerable to the “first night effect,” and consequently, night-to-night variability, the consistency of findings verifies PSG validity (Gurubhagavatula, 2010). When compared to healthy, non-snoring control children, children diagnosed with OSA had a greater
obstructive apnea hypopnea index (OAHI) per hour, as well as a greater respiratory arousal index (RAI) (Walter et al., 2011; Zhu et al., 2014; Gozal & Kheirandish-Gozal, 2008). Additionally, OSA children experienced less time in REM sleep, increased time in NREM stage 1 sleep (N1), and as expected, decreased sleep efficiency (Gozal, 2008; Kadmon et al., 2014; Khalyfa, Serpero, Kheirandish-Gozal, Capdevila, & Gozal, 2011; Ramirez et al., 2013; Walter et al., 2011; Zhu et al., 2014). In particular, the Walter et al. case-control study identified that cortical arousals were far more prominent than subcortical arousals and also that a majority of these arousals terminated in NREM sleep (Walter et al., 2011). This explains the lack of progression through the sleep stages associated with OSA in children. Essentially, the outcome is poor objective sleep quality.

**Consistency of objective and subjective sleep quality measures.** Objective sleep quality characterizes some aspects of the sleep experience not readily captured by subjective measures (Krystal & Edinger, 2008). Clinical history and questionnaires used to screen children for OSA have poor sensitivity and specificity (Katz & D’Ambrosio, 2010). Often times there is a mismatch between objective laboratory PSG data and subjective self-reported sleep quality (Castillo, Goparaju, & Bianchi, 2014). For example, parents of children with OSA do not report sleepiness in over 50% of cases in which the mean sleep latency time is less than 12 minutes, indicating pathological sleepiness (Katz & D’Ambrosio, 2010). Objective measures of sleep quality can be used to improve understanding of the subjective sleep experience and lead to improved treatment of poor sleep quality manifestations.
Impaired Objective Sleep Quality and Short- and Long-term Consequences

OSA is known to cause behavioral and neuropsychological deficits in the central nervous system (CNS) (Yang et al., 2010). The unique sensitivity of the CNS to alterations in oxygen homeostasis demonstrates that neural damage and behavioral consequences observed in OSA patients are associated with intermittent hypoxia (Yang et al., 2010). If left untreated in children, this can result in significant daytime impairments (Figure 4). The Esposito et al. study (2013), assessing the impact of OSA on executive function in a sample of school-aged children, found that children affected by OSA present with lower executive functioning. Executive function includes inhibitory control, attention, reward sensitivity, and working memory (Esposito et al., 2013). Furthermore, parents and teachers both report disruptive behavior including aggression and poor emotional control in children diagnosed with OSA (Katz & D’Ambrosio, 2010).

Because adequate sleep is fundamental for daytime functioning and neurocognitive performance in childhood, there is a concern that persistent OSA during critical central neural developmental intervals may result in lasting neurocognitive deficits (Katz & D’Ambrosio, 2010; Esposito et al., 2013). Intermittent hypoxia may cause structural neuron damage in the cerebral cortex of the brain, which is particularly susceptible to ischemia (Yang et al., 2010). Additionally, the hippocampus region, associated with memory processing, can become atrophic over time in children with OSA. Studies have found that in children with OSA, significant decrements in intelligence quotient (IQ), verbal working memory, and verbal fluency exist (Yang et al., 2010). Though sleepiness is the best characterized symptomatic consequence of OSA, deficits may occur in a variety of brain functions, due to both sleep loss and recurrent hypoxemia (Gurubhagavatula, 2010).
In children, OSA may also trigger the earlier onset and progression of diseases that usually become symptomatic during late adulthood (Gozal & Kheirandish-Gozal, 2008). Recurrent episodes of hypoxemia and arousals associated with OSA activate oxidative stress and systemic inflammatory pathways that are mechanistically involved in the pathophysiology of OSA-associated morbidities (Gozal & Kheirandish-Gozal, 2008; Katz & D’Ambrosio, 2010). The combination of oxidative stress, inflammation, autonomic activation, and disruption of sleep homeostasis results in metabolic and cardiovascular morbidities (Katz & D’Ambrosio, 2010).

OSA severity in children also correlates with an increase in visceral fat deposition, heightening the risk for obesity in early childhood (Bonsignore, Borel, Machan, & Grunstein, 2013). Obesity is associated with insulin resistance, dyslipidemia, and hypertension (Katz & D’Ambrosio, 2010). Having said that, children are vulnerable to acquiring type 2 diabetes as a result of insulin sensitivity deterioration (Bonsignore et al., 2013). Furthermore, sympathetic activation induced by sleep fragmentation and intermittent hypoxia can result in cardiovascular abnormalities ranging from autonomic dysfunction to structural heart disease (Bonsignore et al., 2013; Katz & D’Ambrosio, 2010). Collectively, untreated OSA in children is associated with both short- and long-term functional and health consequences.

**Conclusion**

The evidence to date suggests that OSA in children is often undiagnosed (Marcus et al., 2012). As a result, children with OSA suffer the short- and long-term consequences of poor sleep quality related to sleep fragmentation. Results of the Zhu et al. (2014) study suggest that OSA severity is positively correlated with objective manifestations of the disorder, including objective poor sleep quality. Additionally, the resulting daytime impairments and comorbidities intensify
with increasing OSA severity (Gurubhagavatula, 2010). There is a suggestion that children with untreated OSA are particularly vulnerable to cardiovascular disease and metabolic abnormalities (Gozal & Kheirandish-Gozal, 2008). The current evidence also suggests that to measure sleep quality in children with OSA, an overnight PSG is substantially more reliable than any other objective measure. Still, many of the investigations did not control for night-to-night variability or assess residual sleepiness (Walter et al., 2011). Furthermore, a subjective report of sleep quality should be used only as a supplemental measure, not as a diagnostic indicator.

Unanswered questions remain relative to sleep quality in untreated children with OSA. This study will describe objective sleep quality in children and adolescents with OSA and explore the relationship between a subjective and objective measure of sleep quality within the same cohort. Given that the pediatric population is at a critical period for brain development, identification of children who are at risk for OSA is an important nursing role. By understanding the relationship between objective and subjective sleep quality in children with OSA, the reliability of subjective sleep quality screening alone for OSA in clinical settings will be preliminarily addressed. Evidence indicates there is urgency to establish the diagnosis promptly in suspected childhood cases of OSA as sleep quality impairment imparts deleterious effects on children with OSA. It is imperative to establish evidence-based recommendations for clinical decision-making regarding referral of children for OSA diagnostics.
Figure 2. Literature Review Decision Tree

394 Total articles retrieved
365 PubMed
5 CINAHL
3 PsychINFO
11 Ancestry search

321 Articles excluded by title and abstract
287 Not related to topic
18 Duplicates
16 Not original research

73 Articles reviewed in full text for inclusion

50 Articles excluded after full text evaluation
14 Not related to topic
19 Sleep quality not measured
16 Age exclusion

23 Articles selected for inclusion in the literature review
Models the consequences of recurrent hypoxia seen in obstructive sleep apnea resulting in cardiac strain and metabolic dysfunction. Reprinted with permission from Copyright Clearance Center (Appendix B); original published figure from *Principles and practice of sleep medicine* (Kryger, M., Roth, T., Dement, W., 2005, p. 1371).
Models the effect that OSA-related sleep disruption has on the restorative processes that occur during sleep such that neural function is impaired. Reprinted with permission from Copyright Clearance Center (Appendix B); original published figure from *Principles and practice of sleep medicine* (Kryger, M., Roth, T., Dement, W., 2005, p. 316).
Chapter 3

Methods

Obstructive sleep apnea (OSA) affects approximately 6% of the general pediatric population (Marcus et al., 2012). That is, over 4 million American children are currently diagnosed with OSA. In OSA, respiratory events associated with cortical arousals results in sleep fragmentation (Sawyer & Weaver, 2011). Children with OSA therefore experience poor sleep quality, which is equated with the disruption of the natural architecture of sleep. OSA children are likely to suffer short- and long-term consequences. Furthermore, pediatric OSA is under-recognized and under-diagnosed which contributes to an under-estimation of its prevalence (Marcus et al., 2012). Left unrecognized, OSA confers serious risks. Impaired sleep quality, combined with intermittent nocturnal hypoxia, in OSA are readily overlooked by clinicians because there is inadequate data available to identify OSA at clinical visits and symptoms are often not reported by children or their parents (Marcus et al., 2012). Chronic comorbidities associated with untreated pediatric OSA include cognitive deficits, behavior problems, mood impairments, excessive daytime sleepiness, impaired school performance, and poor quality of life (Alexander & Schroeder, 2013). Additional long-term consequences include the early onset and progression of diseases that usually emerge during late adulthood, such as cardiovascular and metabolic diseases (Gozal & Kheirandish-Gozal, 2008). Sleep quality and the effect that poor quality sleep has on children may not be acknowledged by clinicians due to the lack of data accessible at the time of clinical assessment.
This study aims to (1) describe objective sleep quality, defined by respiratory event related arousals (RERAs), and subjective sleep quality, defined as a single item sleep quality rating on the morning after PSG, in children and adolescents (ages 5-18 years) with obstructive sleep apnea; and (2) explore the relationship between self-reported subjective sleep quality, defined as a single item sleep quality rating collected on the morning after PSG, and objective sleep quality, defined by respiratory event related arousals (RERAs), in children and adolescents (ages 5-18 years) with obstructive sleep apnea. This study is a post-hoc, descriptive analysis of data from a parent study that sought to describe CPAP use, examine patterns of treatment use in children and adolescents with OSA, and explore baseline predictive factors of influence on CPAP adherence. The study was approved by the Institutional Review Board (IRB) at Penn State Hershey Medical Center (PSHMC; Protocol #038839EP).

**Study Design**

A post-hoc analysis of a preexisting data set was conducted. The pre-existing data set is from a retrospective single cohort study. This post-hoc study is designed to specifically describe objective and subjective sleep quality in children with OSA, using previously collected diagnostic polysomnographic (i.e., sleep study) and survey data. The descriptive analysis will address the question: In children and adolescents with obstructive sleep apnea, how do OSA-related cortical arousals disrupt the normal distribution of sleep stages, such that, the disease influences objective sleep quality (sleep stage distribution; wake after sleep onset; respiratory event related arousals; total arousals during sleep) and subjective sleep quality (self-reported sleep quality assessed immediately after awakening)?
**Sampling Plan**

The target population is children and adolescents, ages 5-18 years, diagnosed with obstructive sleep apnea. Diagnosable OSA in children, according to the American Academy of Sleep Medicine (2005), starts at an apnea hypopnea index (AHI) of 1 event per hour.

**Data Accrual.** The parent study data accrual is described first, followed by the inclusion/exclusion criteria for the post-hoc study. An electronic medical record (EMR) coding inquiry was first conducted to identify potential subjects; an EMR query using the following criteria was conducted: pediatric OSA diagnosis code, polysomnography procedure code, age limit >3 years - <19 years, between years of 2008-2012. The EMR query resulted in a list of eligible subjects (n=72). Data accrual was considered complete if a diagnostic PSG report was on file for every participant included.

**Inclusion/Exclusion Criteria.** Employing established inclusion/exclusion criteria for the parent study, a final set of data was established for this post-hoc analysis (n=28). Inclusion criteria were: (1) male or female children and adolescents 5 through 18 years of age, and (2) an OSA diagnosis (AHI of at least 1 event per hour). Participants were excluded if they had a neuromuscular disease or chronic respiratory failure.

**Variables**

The parent study variables included demographic data, polysomnography data, and clinical questionnaire data. The variables for this study include:

**Demographics.** Subject characteristics were accrued from the EMR and polysomnography acquisition database (source documents). The characteristic variables included in this study are age, gender, BMI, and comorbidities.
**Epworth Sleepiness Scale.** The Epworth sleepiness scale (ESS) is a self-reported measure of daytime sleepiness collected at the initial clinical evaluation by a sleep provider. The ESS is a validated measure of subjective sleepiness (Johns et al., 1991) and is widely used in OSA patients to assess sleepiness (Chervin, 2003); the ESS is included in the PSHMC sleep questionnaire completed by all sleep clinic patients. The questionnaire asks, ‘how likely are you to doze off or fall asleep in the following situations, in contrast to just feeling tired?’ The child will rate each of eight circumstances zero to three, with zero being ‘no chance of dozing’ and three being a ‘high chance of dozing.’ As evidenced by the Sleep Heart Health Study, ESS scores correlate with apnea hypopnea index (AHI), a measure used to objectively describe severity of sleep apnea (Chervin, 2003).

**Polysomnography.** Subjects underwent an overnight, diagnostic polysomnography (PSG) at PSHMC sleep center. PSG is a gold standard measure of sleep and objective sleep quality in adults and children (Grigg-Damberger et al., 2007). PSG includes the measures of electroencephalography (EEG), chin/eye/leg electromyography (EMG), electrooculography (EOG), chest and abdomen respiratory efforts, nasal airflow pressure via thermistor, capnography, and pulse oximetry (Miller et al., 2014). PSG measures were scored according to standard criteria (Iber et al., 2007). The scored PSG records include the following variables for the current study:

**Apnea hypopnea index.** The apnea hypopnea index (AHI) characterizes the severity of sleep apnea (AASM, 2005). AHI is defined as the total number of apnea/hypopnea events per hour. Apneas and hypopneas are defined, respectively, as complete and partial airway obstructions that lead to the cessation of breathing (Sawyer & Weaver, 2011). An apnea index
(AI) and hypopnea index (HI) will be used to differentiate the number of obstructive apnea events per hour from the number of obstructive hypopnea events.

**Oxygenation nadir.** The oxygenation nadir (O2 nadir) is defined as the lowest measure of oxygen saturation during NREM sleep (Mahtani, Robinson, Yelland, Sasse, & Conduit, 2011). During apnea and hypopnea events, the cessation of breathing causes hypoxia. Hypoxia results in cortical arousals that terminate the apneic respiratory events.

**Total sleep time oxygenation.** Hypoxia during sleep can result in long-term neurocognitive deficits (Marcus et al., 2012). For the purpose of this study, total sleep time oxygenation (TST O2) is the percentage of minutes during sleep that oxygenation saturation was less than 90%.

**Arousal indices.** Arousals from sleep disrupt the progression of sleep stages such that sleep quality is insufficient. The total arousal index (ArI) describes the number of respiratory/breathing events during sleep that are terminated by subcortical, cortical, or actual arousals. According to the National Sleep Foundation, this includes arousals that are caused by respiratory disturbances as well as arousals caused by increased heart rate, limb movement, and unknown intrusion (2016). Respiratory event related arousals (RERAs) are specific to arousals caused by respiratory events (Tsara et al., 2009). Arousal indices, ArI and RERAs, will be used as a measure of sleep quality indicative of sleep fragmentation. For the purpose of this study, objective sleep quality will be predominantly defined by RERAs.

**Wake after sleep onset.** Wake after sleep onset (WASO) is defined as the duration, in minutes, of actual awakenings after sleep onset (Harvey et al., 2008). This variable will be used in the study to describe the discontinuity of sleep.
Sleep efficiency. The ratio between time spent in bed and total sleep time (TST) is termed sleep efficiency (ASAA, 2015). For the purpose of this study, sleep efficiency is defined as an objective assessment of sleep achievement during the PSG.

Sleep stage distribution. Sleep stage distribution will be described in terms of the percent of total sleep time (% TST) spent in each stage of sleep. The pattern of sleep in a normal young adult is as follows: 2-5% TST spent in stage 1 sleep (N1), 45-55% TST spent in stage 2 sleep (N2), 3-8% TST spent in stage 3 sleep (N3), and 10-15% spent in stage 4 sleep (N4) (Carskadon & Dement, 2011). Non-rapid eye movement (NREM) sleep, therefore, is usually 75-80% of sleep and rapid eye movement (REM) sleep is usually 20-25% of sleep, occurring in four to six discrete episodes (Carskadon & Dement, 2011). For the purpose of this study, % TST per stage will be used to identify the lack of progression through the sleep stages and as a result, the absence of restorative sleep. Percent TST per stage will be described in relationship to published normative sleep stage distribution in children and adolescents ages 5-18 years.

Clinical questionnaire. Immediately following diagnostic PSG, a pediatric post-sleep questionnaire was used to collect subjective data. A single item rating from the questionnaire asking each child, “how well did you sleep last night,” was used to measure subjective sleep quality. The response options were as follows: extremely bad, very bad, bad, average, good, very good, and extremely good. These categories were collapsed for analysis, reducing the response options to three. To reduce the risk of measurement error, binary ratings and a neutral category were used to rate sleep quality. A score of 1 was applied to good, very good, and extremely good ratings; an average rating was given a score of 2, and a score 3 was applied for extremely bad, very bad, and bad ratings.
Data Collection and Study Protocol

The data for this study was extracted from source documents. Electronic medical records (EMRs) and the polysomnography acquisition system database at PSHMC provided the source documents (Figure 5).

Data extraction. A waiver of authorization was approved for the parent study from PSHMC Institutional Review Board; therefore, no informed consent was obtained. Data required for the analysis was extracted from both electronic medical records and polysomnography acquisition system database; all data was extracted from source documents and entered into a research database. Two investigators extracted all data from source documents adhering to a double data entry protocol to minimize data entry error. Any discrepancies were evaluated by a third investigator and corrected.

Data aggregation. Data was aggregated in a research database, accessible only to investigators. A master de-identified database was used for analysis; each column of the database represents a different study variable and each row represents a different subject. One investigator cleaned the data, ensuring integrity and accuracy. After the data cleaning procedure was complete, the master, de-identified database was secured for analysis.

Data Analysis

All research variables were descriptively examined (mean, SD, median, IQR [interquartile range]); normally distributed data is reported as mean ± standard deviation; non-normally distributed data is reported as median (IQR). Sample description includes age, BMI, subjective sleepiness (ESS total score) and comorbidities.
Aim 1: To describe objective sleep quality, defined by respiratory event related arousals (RERAs), and subjective sleep quality, defined as a single item sleep quality rating on the morning after PSG, in children and adolescents (ages 5-18 years) with obstructive sleep apnea.

Objective sleep quality was described using descriptive statistics (measures of central tendency). Diagnostic tests were utilized for variable distribution (i.e. histograms). The objective sleep quality variables derived from polysomnography include: Apnea hypopnea index, oxygenation nadir, total sleep time oxygenation, arousal indices, wake after sleep onset, sleep efficiency, and sleep stage distribution. The distribution of sleep stages (N1, N2, N3, R) were examined as frequencies, percent of total sleep time. Arousals, including respiratory effort related arousals (RERAs), are descriptively reported as indices, number of events per hour.

Subjective sleep quality is described using descriptive statistics (measures of central tendency).

Aim 2: To explore the relationship between subjective sleep quality, defined as a single item sleep quality rating on the morning after PSG, and objective sleep quality, defined by respiratory event related arousals (RERAs), in children and adolescents (ages 5-18 years) with obstructive sleep apnea.

The relationship between subjective and objective sleep quality is described using correlational procedures (Pearson’s product-moment correlation with outliers removed and Spearman’s rank correlation coefficient).

Summary

In conclusion, this analysis provides a description of objective and subjective sleep quality in children and adolescents (ages 5-18) with OSA. Objective sleep quality is described
using PSG measures, including: apnea hypopnea index (AHI), apnea index (AI), hypopnea index (HI), oxygen nadir, total sleep time oxygenation (TST O2), total arousal index (ArI), respiratory-event related arousals (RERAs), wake after sleep onset (WASO), sleep efficiency, and sleep stage distribution. Descriptive statistics and correlational procedures were performed and are reported to address the study aims.
Figure 5. Data Collection Procedures

Electronic medical record (EMR) query

Criteria: OSA diagnosis code, polysomnography procedure code, age limit >3 years and <19 years, PSG between years of 2008 and 2012

N = 72

Inclusion criteria:
(1) Male or female children and adolescents 5-18 years
(2) OSA diagnosis

Exclusion criteria: Diagnosis involving neuromuscular disease or chronic respiratory failure

N = 50

Describes how data was aggregated for this study and the clinical procedures from which data was drawn from to accrue the final data set.
Chapter 4

Results

The purpose of this analysis was two-fold. Using descriptive statistics, Pearson product-moment correlation coefficient with outliers removed, and Spearman’s rank correlation coefficient, this study sought to: (1) describe objective sleep quality, defined by respiratory event related arousals (RERAs), and subjective sleep quality, defined as a single item sleep quality rating on the morning after PSG, in children and adolescents (ages 5-18 years) with obstructive sleep apnea (OSA); and (2) explore the relationship between self-reported subjective sleep quality, defined as a single item sleep quality rating collected on the morning after PSG, and objective sleep quality, defined by respiratory event related arousals (RERAs), in children and adolescents (ages 5-18 years) with obstructive sleep apnea. An additional exploratory analysis was completed to further investigate the relationship between self-reported subjective sleep quality and objective sleep quality wherein sleep efficiency,

\[
\frac{Total \ sleep \ time \ (minutes)}{Time \ in \ bed \ (minutes)}
\]

was employed as an exploratory objective sleep quality variable.

Sample Demographics

The sample included 28 children and adolescents (mean age, 12.03 years ± 3.43), males (61% \[n=17\]) of Caucasian (46% \[n=13\]) or other self-reported race group (25% \[n=7\]) with
severe OSA (mean apnea-hypopnea index, 20.95 events/hour ± 25.53; Table 1). Low oxygenation during the study, measured by continuous nocturnal oximetry, was identified with a mean oxygen saturation nadir less than 88% (mean nadir, 84.10% ± 10.96). The sample did not self-report subjective sleepiness, measured by the Epworth Sleepiness Scale (mean total ESS score, 9.16 ± 5.3). The majority of the sample had one or more comorbidities, including the following: asthma (39% [n=11]), attention-deficit/hyperactivity disorder (25% [n=7]), gastroesophageal reflux disease (29% [n=8]), obesity (57% [n=16]), cardiovascular disease (32% [n=9]), and diabetes mellitus (10% [n=3]). Additionally, based on pediatric guidelines for BMI classification established by the Centers for Disease Control and Prevention (CDC, 2015) the sample was obese (mean BMI, 32.74 kg/m² ± 9.74).

Table 1. Sample Characteristics (n=28)

<table>
<thead>
<tr>
<th>Characteristic Variable</th>
<th>Mean ± SD or n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender, %</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>11 (39)</td>
</tr>
<tr>
<td>Male</td>
<td>17 (61)</td>
</tr>
<tr>
<td>Race/Ethnicity, %</td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>13 (46)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------</td>
</tr>
<tr>
<td><strong>African American</strong></td>
<td>3 (12)</td>
</tr>
<tr>
<td><strong>Hispanic/other</strong></td>
<td>12 (42)</td>
</tr>
<tr>
<td><strong>Age, Years</strong></td>
<td>12.03 ± 5</td>
</tr>
<tr>
<td><strong>Children, % (5-12 years)</strong></td>
<td>13 (46)</td>
</tr>
<tr>
<td><strong>Adolescents, % (13-18 years)</strong></td>
<td>15 (54)</td>
</tr>
<tr>
<td><strong>Comorbidities, %</strong></td>
<td></td>
</tr>
<tr>
<td>Asthma</td>
<td>11 (39)</td>
</tr>
<tr>
<td>ADHD</td>
<td>7 (25)</td>
</tr>
<tr>
<td>GERD</td>
<td>8 (29)</td>
</tr>
<tr>
<td>Obesity</td>
<td>16 (57)</td>
</tr>
<tr>
<td>CV Disease</td>
<td>9 (32)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>3 (10)</td>
</tr>
<tr>
<td><strong>BMI, kg/m²</strong></td>
<td>32.74 ± 9.74</td>
</tr>
<tr>
<td><strong>AHI, events/hr</strong></td>
<td>20.95 ± 25.53</td>
</tr>
<tr>
<td><strong>Oxyhemoglobin saturation nadir, %</strong></td>
<td>84.10 ± 10.96</td>
</tr>
</tbody>
</table>
ESS Score, Total  
9.16 ± 5.3

Notes. Abbreviations: ADHD, Attention-deficit/hyperactivity disorder; GERD, Gastroesophageal reflux disease; CV, cardiovascular; BMI, Body mass index; AHI, Apnea hypopnea index; ESS, Epworth sleepiness scale

Aim 1: Describe objective sleep quality, defined by RERAs, and subjective sleep quality, defined as a single item sleep quality rating on the morning after PSG, in children and adolescents with OSA.

Overnight polysomnography (PSG) was used to evaluate study participants’ obstructive sleep apnea (OSA) (Sawyer & Weaver, 2011). PSG was scored according to standard criteria (Iber et al., 2007). The scored PSG records provided data for objective sleep quality, or RERAs. In addition, other objective sleep quality variables (exploratory research variables) were examined, including total arousal index (ArI), sleep stage distribution (non-REM stage 1 [N1], non-REM stage 2 [N2], non-REM stage 3 [N3] and REM [R]), wake after sleep onset (WASO), and sleep efficiency. The data for all research variables, evaluated by graphical tests, was not normally distributed and therefore nonparametric statistics [median ± (IQR)] are reported. This is also the appropriate reporting approach with small samples (Erceg-Hurn & Mirosevich, 2008).

The sample demonstrated high total arousal index (6.6 ± 9.8) based on normal parameters in children (<5 events/hr; Table 2) (Paruthi & Chervin, 2010). The elevated arousal index is indicative of sleep fragmentation (Ramirez et al., 2013). That said, participants experienced few arousals caused by respiratory events (RERAs, mean events/hr, 0.4 ± 0.8). Sleep stage distribution (i.e., % time in stage) for the sample was: %N1 (4.55 ± 7.7), %N2 (47.5 ± 17.1), %
N3 (24.1 ± 15.97), % R (16.6 ± 9.57). Though, wake after sleep onset was high (36 minutes ± 52.15), sleep efficiency was minimally diminished (median sleep efficiency %, 87.2 ± 9.325).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Median</th>
<th>IQR</th>
<th>Min</th>
<th>Max</th>
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<tr>
<td>ArI (events/hr)</td>
<td>10.47</td>
<td>14.06</td>
<td>6.6</td>
<td>9.8</td>
<td>0</td>
<td>64.4</td>
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<td>RERA (events/hr)</td>
<td>0.82</td>
<td>1.46</td>
<td>0.4</td>
<td>0.8</td>
<td>0</td>
<td>5.7</td>
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<tr>
<td>WASO (minutes)</td>
<td>53.76</td>
<td>53.45</td>
<td>36</td>
<td>52.15</td>
<td>3</td>
<td>250.9</td>
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<tr>
<td>Sleep efficiency (%)</td>
<td>84.4</td>
<td>11.73</td>
<td>87.2</td>
<td>9.325</td>
<td>44.5</td>
<td>97.8</td>
</tr>
<tr>
<td>%N1</td>
<td>5.57</td>
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<td>4.55</td>
<td>7.7</td>
<td>0</td>
<td>21.6</td>
</tr>
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</table>
Subjective sleep quality was defined as a single, self-rated sleep quality item on the morning after PSG questionnaire asking each child, “How well did you sleep last night?” Subjects rated sleep quality as good (n=14, 50%), average (n=9, 32%), or bad/poor (n=5, 18%).

Aim 2: Explore the relationship between self-reported subjective sleep quality, defined as a single item sleep quality rating collected on the morning after PSG, and objective sleep quality, defined by respiratory event related arousals (RERAs), in children and adolescents (ages 5-18 years) with obstructive sleep apnea.

A weak, positive correlation between self-reported subjective sleep quality and RERAs was identified as demonstrated by Spearman’s correlation statistic (r = 0.13, p = 0.505). That said, the correlation lacks statistical significance, and additionally, when we examine the scatter plot (figure 6) there is no relationship apparent between RERAs and subjective sleep quality. This correlation was examined with outliers removed and there was no difference in the results. We acknowledge that Pearson’s correlation has underlying assumptions that were not met in this

<table>
<thead>
<tr>
<th></th>
<th>%N2</th>
<th>16.56</th>
<th>47.5</th>
<th>17.1</th>
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<tbody>
<tr>
<td>%N3</td>
<td>31.63</td>
<td>18.68</td>
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<td>%REM</td>
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<td>16.6</td>
<td>9.57</td>
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study including small sample size, non-normally distributed data, and rank ordered data (subjective SQ); therefore, these results were not reported. An additional exploratory analysis was completed to explore the relationship between self-reported subjective sleep quality and objective sleep quality, measured as sleep efficiency. A significant positive relationship was identified (Spearman’s $r = 0.69$, $p = 0.01$). The scatter plot (Figure 7) illustrating the relationship suggested by Spearman’s correlation between sleep efficiency and subjective sleep quality identified an increasing monotonic trend.

**Conclusion**

The sample of this descriptive analysis demonstrated poor objective sleep quality when operationalized as sleep efficiency in the pediatric OSA sample. When objective sleep quality was operationalized as RERAs in this study, sleep quality was not impaired based on normal parameters for RERAs in children with OSA. Many participants reported that they perceived their sleep during the night of the study as “good.” No relationship existed in this sample between RERAs and an individual’s perception of sleep quality (i.e., subjective sleep quality). A statistically significant relationship was identified between self-reported subjective sleep quality and objective sleep quality, defined as sleep efficiency. Examining the scatter plot, an increasing monotonic trend is identified.

**Figure 6. The Relationship Between RERAs and Subjective Sleep Quality (n=28)**
Scatterplot of RERAs (y axis) and Subjective Sleep Quality (x axis). Sleep quality rating scale:

1, Bad; 2, Average; 3, Good.
Figure 7. The Relationship Between Sleep Efficiency and Subjective Sleep Quality (n=28)

Scatterplot of Sleep Efficiency (y axis) and Subjective Sleep Quality (x axis). Sleep quality rating scale: 1, Bad; 2, Average; 3, Good.
Chapter 5

Discussion

This study investigated the relationship between objective and subjective sleep quality in pediatric obstructive sleep apnea (OSA). Subjects underwent an overnight, diagnostic polysomnography (PSG) during which recorded parameters were scored and used as measures of objective sleep quality. Specifically, objective sleep quality was defined by respiratory event related arousals (RERAs). An exploratory analysis was additionally completed where objective sleep quality was defined by PSG-derived sleep efficiency. Subjective sleep quality was assessed immediately following diagnostic polysomnography using a single item rating from a pediatric post-sleep questionnaire.

The sample of pediatric clients demonstrated poor objective sleep quality, defined by sleep efficiency but objective sleep quality was not impaired when defined only by RERAs. Many participants (n=14, 50%) rated sleep quality as good. No significant relationship between self-reported subjective sleep quality and RERAs existed, but a possible decreasing monotonic trend was identified via scatter plot. A significant relationship existed between self-reported subjective sleep quality and sleep efficiency. The association by scatter plot was an increasing monotonic relationship.

Objective Sleep Quality in Children With Obstructive Sleep Apnea

Objective sleep quality variables, measured by PSG, included apnea hypopnea index (AHI), oxygenation nadir, total sleep time oxygenation (TST O2), total arousal index (ArI), respiratory event related arousals (RERAs), wake after sleep onset (WASO), sleep efficiency,
and sleep stage distribution. Of particular importance in this study were RERAs, sleep efficiency, and sleep stage distribution.

**Respiratory Event Related Arousals (RERAs).** This study identified that the sample experienced relatively infrequent RERAs (mean events/hr, 0.4 ± 0.8). Prior studies suggest that RERAs are uncommon in children; that is, children do not necessarily demonstrate respiratory events during sleep that increase the number and duration of arousals (Muzumdar & Arens, 2008). Furthermore, the American Academy of Sleep Medicine (AASM) guideline for pediatric criteria lists RERAs as an optional parameter for assessment of OSA in children (Accardo, Shults, Leonard, Traylor, & Marcus, 2010).

In adults with OSA, respiratory events during sleep often cause sleep fragmentation and impact sleep stage distribution during the sleep bout (Carskadon & Dement, 2011). However, what is known about sleep in adults with OSA cannot be applied to the pediatric population. With very few RERAs occurring in children with OSA, sleep may not be fragmented by respiratory events, consistent with this study’s results.

**Sleep Efficiency.** According to the American Sleep Apnea Association, people who have significant difficulties in initiating or maintaining sleep have diminished sleep efficiency (<85%). The mean sleep efficiency of participants in this study was diminished (84.4%). It is known that aging decreases the brain’s ability to consolidate sleep and therefore adults have slightly lower sleep efficiency than children; when sleep disorders are factored in, sleep efficiency in both groups decrease below the threshold of 85%. The mean sleep efficiency in this study demonstrates abnormal sleep efficiency for children (Wolfson & Montgomery-Downs, 2013). Though this may be due to the presence of OSA in the sample, this may also be related to the artificial environment of sleep in the laboratory testing setting.
Sleep Stage Distribution. Typically, the normal young adult spends 2-5% of total sleep time (TST) in stage 1 sleep (N1), 45-55% TST in stage 2 (N2), and 3-8% TST in stage 3 (N3); rapid eye movement (REM) sleep is usually 20-25% of the sleep bout (Carskadon & Dement, 2011). In this study, participants spent excess time in N3 (24.1 ± 15.97). They also did not achieve sufficient REM sleep (16.6 ± 9.57) as a result of the progression of non-respiratory related arousal events (6.6 ± 9.8) throughout the sleep bout (Goh, Galster, & Marcus, 2000). These arousals fragmented sleep, and as such prevented the progressive nature of sleep stage distribution, particularly REM. Such fragmentation has the ability to cause regression of sleep stages (Sawyer & Weaver, 2011). This would explain the increased time to onset of REM (i.e., REM latency) and ultimately decreased REM sleep observed in this sample. Decreased time spent in REM could have lasting clinical implications on children as this stage is considered the time during which the brain “learns” from the experiences of the day (El Shakankiry, 2011). Additionally, many participants in this study exhibited excess awakenings after the onset of sleep. As seen in prior studies, this discontinuity of sleep is typical in OSA and often degrades the overall quality of sleep causing sleep to be light and less restorative (Gozal, 2008; Kadmon et al., 2014; Khalyfa et al., 2011; Ramirez et al., 2013; Walter et al., 2011; Zhu et al., 2014).

Subjective Sleep Quality in Children With Obstructive Sleep Apnea

Subjective sleep quality was assessed using a single, self-rated sleep quality item on a questionnaire given the morning after PSG. The questionnaire asked each child, “How well did you sleep last night?” The majority of the subjects rated sleep quality as good (50%) or average (32%). It is known that clinical questionnaires used to screen children for OSA have poor reliability (Katz & D’Ambrosio, 2010). Though the single item from the questionnaire used in
this study was not previously validated, the results are consistent with prior pediatric OSA studies where children tend to rate subjective sleep quality as average or good (Krystal & Edinger, 2008).

**Relationship Between Objective and Subjective Sleep Quality in Children With Obstructive Sleep Apnea**

**Objective Sleep Quality, Defined by RERAs, and Subjective Sleep Quality.** The absence of a relationship between RERAs and subjective, self-reported sleep quality may be attributed to a lack of objective sleep quality variability, when defined by RERAs. Consistent with prior pediatric sleep studies, most subjects did not experience many RERAs (Beck & Marcus, 2009); this made it difficult to identify a relationship. It is also likely that this study is underpowered and therefore, the risk of Type II error must be acknowledged. Due to the absence of a relationship between objective and subjective sleep quality, there are clinical implications for how we screen for OSA. Because children and adolescents do not experience RERAs similar to those experienced in adulthood (Beck & Marcus, 2009), simple screening of subjective sleep quality is not likely sensitive to OSA. Rather, a screening tool specific to OSA should be used to assess children with risk factors for developing OSA.

**Objective Sleep Quality, Defined by Sleep Efficiency, and Subjective Sleep Quality.** The increasing monotonic relationship identified between sleep efficiency and subjective, self-reported sleep quality suggests that as sleep efficiency increases, a child’s perception of their sleep to be positive also increases, and vice versa. However, subjective sleep quality was immediately assessed after awakening and therefore, the results apply only to subjective
screening immediately post sleep bout. Furthermore, while this sample of children and adolescents with predominantly severe OSA, accurately perceived impaired sleep efficiency, it is important to acknowledge that sleep efficiency isn’t necessarily impaired in children with OSA. Therefore, simplistic screening for sleep quality perception, or subjective sleep quality, is not recommended for clinically screening children with suspected OSA.

**Study Limitations**

Given that this study was a post-hoc analysis of a preexisting data set, there are several limitations that must be acknowledged. The biggest limitation of performing a secondary analysis is that the research questions for the analysis were not designed *a priori*, but rather after the data existed (Boslaugh, 2007). The data set was not necessarily designed/accrued to answer the questions addressed for this study. Using previously collected data limited the sample available to be pooled for analysis. After eliminating incomplete diagnostic PSG reports and removing subjects previously receiving treatment for OSA, the final sample size was smaller than anticipated (n= 28). This study’s lack of power due to small sample size limited the analysis to non-parametric procedures relative to sample size and distribution of data. In addition, due to a risk of Type II error with small sample size, the results of the study must be considered preliminary or exploratory.

Furthermore, due to the limited size of the data set, RERAs within sleep stages were not examined. As the overall objective was to examine both objective and subjective sleep quality, RERAs in any one sleep stage might be more impactful on an individual’s perception of sleep quality. Though RERA distribution within sleep stages was not an objective of this study, further exploration of this potential explanatory factor would strengthen the results.
Finally, the participants in this study were clinical patients undergoing clinical polysomnograms. As such, the artificial environment of the laboratory setting likely contributed to abnormal sleep architecture as PSG data is vulnerable to the “first night effect,” and consequently, night-to-night sleep variability (Verhulst, 2006). Additionally, the use of a clinical questionnaire single-item for subjective sleep quality, not previously validated for research purposes, may not necessarily measure the construct of interest, subjective sleep quality, as intended.

**Recommendations for Future Research.** While asking a simple question about sleep quality in the clinic may accurately reflect overall sleep quality, it is possible that this method is not sufficient for screening for OSA. It is important to note that subjective sleep quality was measured immediately after the sleep period upon awakening. Future research might utilize a different study design to take into consideration the period of recall when assessing subjective sleep quality. This could be done by measuring and comparing perception of sleep quality both immediately post-sleep and later in the day. Clinical use of simplistic subjective sleep quality screening would be better supported with this evidence. Other validated measures of subjective sleep quality should be used in future studies to increase validity of results. Furthermore, future studies of sleep quality in children might benefit from including an adaptation night in the laboratory or consider employing home sleep studies to permit children to sleep in their natural environments, which potentially improves upon validity and reliability of the results.

Additionally, to draw a reliable conclusion regarding the relationship between objective sleep quality and self-reported subjective sleep quality, future studies should consider stratified sampling to better represent children who experience both poor and sufficient objective sleep quality, specifically when defined by RERAs, as measured by PSG, and additionally to increase
sample size. It is possible that the two PSG variables used to define objective sleep quality in this study do not incorporate enough variability to confirm the existence of a relationship between objective and subjective sleep quality. Future studies may benefit from analyzing other objective variables of sleep quality, as measured by PSG, that may be more accurate/precise for OSAS than RERAs, as children don’t have RERAs as frequent as in adulthood (Beck & Marcus, 2009). These variables might include sleep stage distribution (SWS, REM), ArI, AHA, HI, AI, O2 nadir, and/or PaCO2 via capnography. Larger studies with greater variability in OSAS severity can explore this. It might also be beneficial to consider arousals by type (respiratory and non-respiratory) within the different stages of sleep. A decreased subjective perception of sleep quality may be related to arousals predominantly found in one particular sleep stage over another. Furthermore, different results may be yielded if the duration of RERAs is taken into account. If a child has RERAs of increased duration, the ability to perceive RERAs may increase which may influence the relationship between objective sleep quality as measured by PSG and an individual’s subjective perception of sleep quality.

Clinical Implications

As seen in this study, children may reliably perceive quality of sleep when assessed in close proximity to their sleep bout; however, this post-hoc analysis of pre-existing data did not include longitudinal data, therefore period of recall accuracy cannot be addressed. Furthermore, overall sleep quality assessment by a simplistic survey item is not sensitive to OSA in children with OSA. This means that screening for OSA in children cannot be reliably and accurately assessed by sleep quality screening. In the clinical setting, we cannot recommend rapid screening of subjective sleep quality. Validated tools, with increased sensitivity and
specificity, such as the modified STOP-BANG tool for identifying obstructive sleep apnea risk in adolescents and children is recommended for use in the clinical setting, whether in primary care or pediatric centers. The modified STOP-Bang questionnaire includes subjective assessment of the client for snoring, sleepiness, observed apneas, BMI >95th percentile, academic problems, neck circumference >95th percentile, age, and male gender (Combs, Goodwin, Quan, Morgan, & Parthasarathy, 2015). The number of positive responses calculates the client’s score. Based on this rating, providers can decide if a child has a high likelihood of OSA or not. It would be logical to assume that clients with increased ratings would also exhibit poor objective sleep quality as measured by PSG parameters.

Conclusion

We can conclude that our sample had impaired objective sleep quality, as measured by PSG parameters, typical of children diagnosed with OSA. Though the results of this study are preliminary/exploratory, future research is needed to further explicate the relationship between objective and subjective sleep quality in the pediatric OSA population as clinical screening for sleep impairments is a necessity for the potential reduction in significant health and functional risks of OSA in children. Such routine screenings have the opportunity to mediate short- and long-term consequences of the disease. Daytime impairments, such as poor emotional stability and an increase in hyperactive and inattentive behavior are often seen in children with OSA (Gozal, 2008). Furthermore, physiologic evidence suggests poor sleep efficiency, often seen in OSA, is associated with decreased parasympathetic nervous system activity and increased sympathetic nervous system activity; this results in increased heart rate, blood pressure, and norepinephrine and cortisol release (Colten, Altevogt, Institute of Medicine (U.S.), & Committee
on Sleep Medicine and Research, 2006). Consequences include increased morbidity, mortality, and risk for other medical conditions; for example, cardiovascular disease, deleterious immune system deficits, glucose metabolism and endocrine dysfunction disorders (El Shakankiry, 2011; Sawyer & Weaver, 2011). Higher-level cognitive functions, such as cognitive flexibility and the ability to think abstractly, are also affected by disturbed sleep (El Shakankiry, 2011).

Overall sleep quality assessment by a simplistic survey item is not sensitive or specific to OSA in children. Screening for OSA in children cannot be reliably or accurately assessed by simplistic self-report of sleep quality. Rather, OSA screening should include use of validated OSA screening tools, such as STOP-BANG for children, to identify possible OSA; with a positive screening, follow up by PSG is necessary. Healthcare providers may then begin the treatment discussion earlier. Children who receive OSA treatment at an early age show major improvements in PSG parameters (Marcus et al., 2012). Identifying and understanding the relationship between subjective reports of sleep quality and objective measures is important to provide evidence to support clinical interventions to mediate short- and long-term consequences of OSA in the pediatric population.
Appendix A

Institutional Review Board (IRB) Approval

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<tr>
<td>From:</td>
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<tr>
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<td>Amy Sawyer</td>
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<th>Type of Submission:</th>
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<td>Health Care Utilization in Children with Complex Respiratory Medical Needs</td>
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<td>Amy Sawyer</td>
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<td>Documents Approved:</td>
<td>1. Protocol Abstract.pdf (0,01), Category: IRB Protocol</td>
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On 5/15/2015, the IRB approved the above-referenced Modification and Continuing Review. This approval is effective through 5/14/2016 inclusive. You must submit a continuing review form with all required explanations for this study at least 45 days before the study's approval end date. You can submit a continuing review by navigating to the active study and clicking 'Create Modification / CR'.

If continuing review approval is not granted before 5/14/2016, approval of this study expires on that date.

In conducting this study, you are required to follow the requirements listed in the Investigator Manual (IRP-103), which can be found by navigating to the IRB Library within CATS IRB (http://irb.psu.edu). These requirements include, but are not limited to:

- Documenting consent
- Requesting modification(s)
- Requesting continuing review
- Closing a study
- Reporting new information about a study
- Registering an applicable clinical trial
- Maintaining research records

This correspondence should be maintained with your records.
# Appendix B

## Copyright Clearance

### Order Details

**Principles and practice of sleep medicine**

- **Order detail ID:** 68168456
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- **Publisher:** ELSEVIER/SAUNDERS
- **Author/Editor:** Kryger, Meir H.; Roth, T.; Dement, William C.

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(Cardiovascular Effects of Sleep-Related Breathing Disorders) Page 1371  
Figure 119-1, Sleep Breathing Disorders Part II  
/ Section 13 Page 1200  
Figure 104-4 (OSA and Prefrontal Functioning) |
| Title of the article or chapter the portion is from | Cardiovascular Effects of Sleep-Related Breathing Disorders, Sleep Breathing Disorders |
| Editor of portion(s)            | Mann DL and N/A                                                     |
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*SLEEP-NEW YORK THEN WESTCHESTER*, 31(3), 383.


breathing: EEG spectral analysis compared with conventional polysomnography. *Sleep, 33*(9), 1165.


ACADEMIC VITA
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Thesis Supervisor: Amy M. Sawyer, Ph.D., R.N.

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Archer & Greiner, P.C., Haddonfield, NJ
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• Conducted general research related to cases
• Drafted memos for partners

May 2014 - August 2014 Nursing Assistant, Float Aide
Cape Regional Medical Center, Cape May Court House, NJ
• Provided hands-on care to patients primarily in the telemetry unit and ICU

• Performed routine clinical tasks including vital signs and AM/PM care

• Assisted in the assessment of patients under supervision of registered nurses; Performed electrocardiograms, collected and evaluated laboratory cultures

CLINICAL EXPERIENCE:

2012 - 2016

Student Nurse

The Pennsylvania State University, University Park, PA and Hershey, PA

• Nursing care of the adult client with complex health problems, community and family health nursing, mental health nursing, nursing care of children and adolescents, nursing care of the childbearing family and gynecological client, nursing care of the medical-surgical client, nursing care of the older adult, fundamentals of nursing care

• Clinical Capstone: Aria Health Bucks Campus Emergency Department
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**RESEARCH:**

2014 - Present

**Undergraduate Thesis in Sleep: The Relationship Between Sleep Quality and Obstructive Sleep Apnea In the Pediatric Population**

*The Pennsylvania State University, University Park, PA*

**Adviser:** Amy M. Sawyer, Ph.D., R.N.

- Explored the effects of obstructive sleep apnea on sleep quality in children
- Cleaned and managed data from parent study, planned analysis, interpreted results, developed abstract

April 2015

**Shaping the Future Summit**

*The Pennsylvania State University, University Park, PA*

**Supervisor:** Darlene Clark, M.S., R.N.

- Studied the interaction of ethical, legal, and genetic issues as they apply to health care organizations
- Facilitated a discussion focused on global issues and leadership scenarios, particularly related to "The Power of Money" in organizations that influence health care practice.

**LICENSURE/CERTIFICATIONS:**

2012 - Present  
Basic Life Support (BLS) Provider from American Heart Association

2014 – Present  
Emergency Care and Safety Institute (ECSI) Certification

2016 - Present  
Institute for Healthcare Improvement Basic Certification

2016 - Present  
Crisis Resource Management Training from Penn State Milton S. Hershey Medical Center

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2015 - Present  
Member, Eastern Nursing Research Society

2014 - Present  
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2012 - Present  
Member, Student Nurse Association of Pennsylvania (SNAP)

2012 - Present  
Member/Philanthropy Chair, Gamma Rho Chapter of the Alpha Phi Fraternity

**PROFESSIONAL PRESENTATIONS:**

2016  
DiVincenzo, M., Watach, A., Sawyer, A.M., Mogle, J. The

CONFERENCES ATTENDED: