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The Impact of School Start Times on Adolescent Sleep Duration and Academic Performance

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THE IMPACT OF SCHOOL START TIMES ON ADOLESCENT SLEEP DURATION AND ACADEMIC PERFORMANCE

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Abstract

In terms of sleep, adolescence is a tumultuous time. Biologically, adolescents are more inclined to have a later circadian rhythm and an evening chronotype, causing them to fall asleep later in the night and wake up later in the morning compared to their preadolescent counterparts. Adolescents also must contend with the emergence of environmental factors such as less parental influence over bedtimes, increased caffeine use, part-time employment, increased electronic use before bed, and earlier school start times. The emergence of these biological and environmental factors during puberty negatively affects adolescent sleep duration and adolescent sleepiness is often observed in early morning classes in school. Likewise, due to the synchrony effect, adolescents may not perform to their best ability on morning academic tasks. A possible solution often proposed by school districts to decrease adolescent sleepiness in school is to delay secondary school start times, with multiple professional organizations recommending schools should start no earlier than 8:30 am. Given the connection school start times have with sleep duration and the connection sleep has with cognitive functions, the research summarized in this literature review seeks to determine the extent to which school start times impact sleep duration, sleep duration impacts academic performance, school start times impact attendance and tardy rates, and school start times impact academic performance in order to determine if delaying school start times is a worthwhile endeavor.

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CHAPTER I: INTRODUCTION

Research Justification

At roughly 5:55 am each school day when this researcher is just rolling out of bed to get ready for my 7:40 am teaching job in Rochester, MN, the high school students who live in the farthest outskirts of the school district are getting on the school bus to start their day. At 5:55 am in the morning. Assuming those students want to eat breakfast, shower, or partake in other tasks to get ready for the day, they must wake up well before 5:55 am in order to do so. Assuming some of those students take part in extracurricular activities, work a part time job, or were up late doing homework, their bedtimes may be much later than ideal. The students' early arousal times coupled with their late bedtimes lead to chronic sleep deprivation that is all too often observed in the middle school and high school settings.

As a high school special education teacher, many of the students this author serves are already at a disadvantage when it comes to academic performance. One can assume that adding sleep deprivation to the equation would hinder rather than help such students academically. All too often, this researcher has observed teachers in early morning classes vie for the attention of sleepy and inattentive students. Likewise, all too often, it has been observed that students continuously are tardy to class because they said they have overslept and could not get out of bed. These situations, which appear to contribute to inefficiency in early morning learning, have caused me to question what, if anything, the school could do to ensure students arrive at school awake and ready to learn. A logical first thought would be to make the school start time later to allow students to obtain more sleep, a topic that has been studied extensively and considered by many school districts across the country.

Overview of Sleep and Cognition

The role that sleep deprivation plays on cognition and other brain functions has been well studied and documented, and school districts should prioritize adolescent sleep as a critical topic of discussion as a result. Several meta-analyses exist summarizing the findings of the impacts of sleep deprivation on different domains of cognition. Lim and Dinges (2010) conducted a meta-analysis on 147 data sets found within 70 articles examining the effect size of sleep deprivation on different areas of cognition. These researchers found that a sleep deprivation period of 24 to 48 hours has a statistically significant small to large effect on simple attention, complex attention, processing speed, working memory and short term memory, with the largest effect size being on simple attention which include vigilance tasks.

Lowe, Safati, and Hall (2017) conducted another meta-analysis on the effects of sleep restriction on cognitive functions. Their study analyzed the data from 61 studies and 886 effect sizes to determine the impact that a sleep restriction period of anywhere from one to 10 days could play on cognition. The researchers determined that restricted sleep has statistically significant effects of varying degrees on overall cognitive processing, sustained attention, overall executive functioning, working memory, inhibitory control, and long term memory, with the largest effects being on sustained attention and executive functioning. Lowe et al. (2017) also determined that "the magnitude of the effect progressively increases over cumulative days of restricted sleep"

(p. 600), indicating that the more sleep deprived one is, the greater the impact such deprivation has on cognition.

The impact of sleep restriction on complex versus simple cognitive tasks was examined by Wickens, Hutchins, Laux and Sebok (2015) in their meta-analysis. Their meta-analysis analyzed studies that provided data on cognitive tasks that utilized working memory, multitasking, decision making, or tasks that involved working on a team. While the researchers concluded that sleep restriction has a more profound effect on simple cognitive tasks, they determined that the more complex cognitive tasks are also impacted. Wickens et al. (2015) determined that a full day of total sleep deprivation is associated with a 10% decrease in performance on complex cognitive tasks and each consecutive night of receiving less than four hours of sleep is associated with a 7% decrease in performance on complex cognitive tasks.

Further individual studies examining sleep restriction and cognition support the findings of the meta-analyses. Lufi, Tzischinsky, and Hadar (2011) found that eighth grade students who obtained more sleep performed better on assessments measuring attention levels. In this study, students in the experimental group obtained 55 more minutes of sleep per school night for one week compared to the control group, and at the conclusion of the week when given two assessments measuring attention, including sustained attention, the experimental group performed much better. Like the findings by Wickens et al. (2015), Randazzo, Muehlbach, Schweitzer, and Walsh (1998) determined that sleep restriction can affect more complex cognitive functions as well. Their study, which consisted of an experimental group that obtained five hours of sleep for one night and a control group that obtained 11 hours of sleep for one night, found that children in the experimental group performed much worse on tasks involving creativity, verbal processing, and abstract thinking the next day.

Professional Recommendations and National Data

Given the role that sleep plays on cognition, different professional organizations have provided recommendations on how much sleep students should receive. Hirshkowitz et al. (2015), representing a panel of experts assembled by the National Sleep Foundation recommended that six to 13 year olds, the age range that includes young adolescents, should obtain nine to 11 hours of sleep per day. The same panel recommended that 14 to 17 year olds should obtain eight to 10 hours of sleep per day. Maximizing the physical, emotional, and cognitive health of individuals formed the basis for these recommendations and these recommendations were made by the panel based on research linking sleep duration to academic performance and cognitive functioning.

Likewise, to maximize adolescent sleep, professional organizations have provided recommendations on secondary school start times. Policy statements issued by the Society of Behavioral Medicine (SBM), the American Academy of Sleep Medicine (AASM), and the American Academy of Pediatrics (AAP) argued that middle school and high school starting times should be no earlier than 8:30 am in order to maximize adolescent sleep (Trevorrow, Zhou, Dietch & Gonzalez, 2019; Watson et al., 2017; Adolescent Sleep Working Group, Committee on Adolescence, and Council on School Health, 2014). In addition to allowing adolescents a chance to obtain optimal sleep, the AASM argued that such start times would aid in decreasing tardy and absence rates in school, in maximizing adolescent alertness in school, and in improving adolescent mental health and driving safety (Watson et al., 2017). Likewise, the SBM argued that with such school start times, the work schedules of teachers wouldn't need to change as all prepping and staff development could occur before school, the morning routines of families may be less disorganized due to adolescents being more rested, the schedules of extracurricular activities would not need to change drastically, and school busses could bring elementary students to school before secondary students (Trevorrow et al. 2019).

Despite the recommendations on school start times provided by the SBM, AASM, and AAP, the 2017-2018 National Teacher and Principal Survey (NTPS) revealed that the average start time for public secondary schools across the United States is 8:00 am (Sawyer & Taie, 2020). Sawyer and Taie (2020) revealed that while some types of schools are more inclined to have a later start time such as charter schools and schools with small enrollments, 54% of suburban high schools and 54% of schools with an enrollment above 1,000 students start school before 8:00 am. Ten percent of all public high schools start school before 7:30 am, one full hour before the recommended time provided by the professional organizations previously cited. Eighty-two percent of all public high schools in the U.S. start school before 8:30 am. The average start time in four states, New Hampshire, Massachusetts, Connecticut, and Louisiana, is earlier than 7:45 am with the lowest average start time being 7:30 am in Louisiana.

Barriers to School Start Time Changes

Even though multiple professional organizations have recommended secondary schools start at 8:30 am or later, many districts appear reluctant to make such policy changes and cite barriers that impede such changes. When conducting her School Start Time Study, Wahlstrom (2001) found that different stakeholder groups convey varying hesitations to school start time changes. For instance, people in charge of transportation reiterated the need for schools to have staggered start times to keep transportation costs low and conveyed safety concerns about the potential for elementary school students to start school first in the morning when it's still dark out. People involved in athletics showed concerns that a later high school start time would impact sports teams' ability to fit practices and games in while it's still light out and showed concerns regarding event scheduling in high demand sports facilities that are also used by other groups in the community. Likewise, community education staff indicated later secondary school start times would make scheduling facility use much more difficult.

In a survey conducted by Wolfson and Carskadon (2005), staff of high schools which recently went through a start time change or were considering a start time change listed similar barriers to such a policy change. Fifty-five percent of respondents listed changes to athletic practices as a barrier, 26% listed changes to after school activities as a barrier, and 30% listed the cost of modifying the transportation system as a barrier. Other barriers to a school start time change listed often were parental concerns, teacher concerns and concerns about childcare before and after school.

One important stakeholder group whose opinion can serve as a barrier to school start time changes are parents. For parents of students with school start times before 8:30 am, Dunietz et al. (2017) found that roughly the same number of parents oppose a delay in school start times as those who support it. Parents were more likely to oppose a delay of school start times to 8:30 am if they believed such a delay would negatively impact their daily routines such as interfere with transportation logistics, interfere with activities after school, and interfere with meal times after school. Parents were more likely to support a school start time delay if they anticipated positive outcomes from the delay such as more sleep for their students and increased academic performance, and if they agreed with the AAP recommendations on school start times. Given the discrepancy between parents that oppose and support school start time delays and in order for more schools to enact a school start time of 8:30 am or later as recommended by the AAP, Dunietz et al. (2017) calls for “broader parental education about AAP recommendations and academic benefits of SSTs [school start times],” as well as “invigorated efforts to educate parents about sleep health of teens” (p. 893).

As it is so often pointed out, delaying secondary school start times is no easy undertaking. As pointed out by Wahlstrom (2001), the decision to enact a school delay policy change is “highly politically charged and extraordinarily complex” (p. 194). She implies the importance of addressing the apprehensions and needs of each stakeholder group regarding school start time delays and acknowledging how each group is interrelated in order to avoid the wrong decision from being made. Given the perceived barriers to delaying school start times, school districts need to first determine whether the benefits to students' sleep health and academics outweigh the costs of such barriers.

Sleep Study Terms

Circadian Rhythms

According to Carskadon (1999), circadian rhythms are biological oscillations that occur within our bodies with cycles that roughly follow the 24-hour day. Driven by our biological clocks, circadian rhythms control processes that inhibit or promote sleep, such as the onset of rapid eye movement (REM) sleep and the release of melatonin. The onset of certain biological processes that occur within our body can determine what phase the circadian rhythm is in (Carskadon, 1999).

Chronotype

Kirby, Maggi, and D'Angiulli (2011) defined chronotype as the time of day preference individuals show to be asleep and to be awake. Having a morning preference or an evening preference would be considered two extreme chronotypes. Similarly, Crowley, Acebo, and Carskadon (2007) explained, "Phase preference, or morningness/eveningness is a behavioral construct related to the time of day best suited for waking behavior" (p. 606). Put more simply, Carskadon (1999) explained that "phase preference refers to an individual's tendency to favor activities in the morning or evening, i.e. morningness/eveningness" (p. 350). Roenneberg et al. (2004) defined chronotype as when a person's circadian rhythm syncs up with the 24-hour day and explains that some rhythms sync up late in the day while others sync up earlier in the day.

Melatonin

Carskadon (1999) explained that melatonin is a hormone produced by the body and its release is managed by circadian rhythms. Its release occurs during the nighttime hours and saliva samples taken in low light conditions are often used to measure the secretion of melatonin. Lewy and Sack (1989) as cited in Carskadon (1999) found that melatonin secretion is a great way to determine the phase that the circadian rhythm is in to determine biological clock time.

Thesis Questions

Given the apparent prevalence of sleepy adolescents in secondary schools and a possible solution proposed in many school districts being to delay school start times, this thesis seeks to answer multiple questions through a literature review in order to determine if such a policy change would be worthwhile. The questions are as follows:

- To what extent do school start times impact adolescent sleep duration?
- To what extent does sleep duration impact adolescent academic performance?
- To what extent do school start times impact attendance and tardy rates in school?
- To what extent do school start times directly impact adolescent academic performance?

These questions will be addressed through the research surrounding sleep changes that occur during adolescence followed by research justifying school start time delays.

CHAPTER II: LITERATURE REVIEW

Research Search Explanation

Research was gathered by using the Bethel University library's CLICsearch tool and Google Scholar. In each search tool, different combinations of the terms "adolescent", "adolescence", "sleep duration", "academic performance", and "school start time" were used. In order to gather further information regarding the sleep patterns and sleep changes that occur during adolescence, further search terms included "sleep patterns", "delayed phase preference", "chronotype", and "circadian rhythms". The selected journal articles were ones that were peer reviewed and most articles came from the databases of ScienceDirect, PubMed Central, JSTOR, and EBSCOhost. In addition, further sources were found from the citations and references pages of previously downloaded and read journal articles. The following chapter summarizes the sleep changes caused by biological and environmental factors that impact adolescent sleep, the synchrony effect, the impact sleep duration has on academic performance, and the impact school start times have on sleep duration, attendance and tardy rates, and academic performance.

Sleep Changes During Adolescence

Biological Factors

To better understand the impact that school start times have on adolescents, one would benefit from first determining how adolescent sleep is different to the sleep of people in other age groups. Luckily, there is a substantial body of research from the 1990's and early 2000's that study the biological sleep changes that occur during adolescence. Mary A. Carskadon, a pioneer in sleep research, is accredited for many of these studies along with her colleagues. In 1993, Carskadon, Vieira, and Acebo hypothesized that the tendency for teenagers to exhibit a circadian phase delay, or a tendency for teenagers to fall asleep and wake up later than their preadolescent counterparts, is a result of biological factors. Carskadon et al. (1993) surveyed sixth graders using a morning/eveningness scale developed by Carskadon and Acebo and a physical development survey to determine their chronotype and the stage of puberty they were in. The researchers found that the sixth graders' weeknight bedtimes were positively related to their puberty stage; the students with the higher puberty stage had later bedtimes and more of a preference towards the eveningness chronotype. This relationship was more significant for the sixth-grade girls, mainly because girls tend to go through puberty sooner than boys.

Further studies from around the world corroborate the findings of Carskadon and her colleagues. In Spain, Diaz-Morales and Gutierrez Sorroche (2008), using a Spanish version of the same morningness/eveningness scale used by Carskadon et al. (1993) found an increased tendency towards eveningness with increased age when they studied 12 to 16 year olds. Likewise, in Germany, Randler (2011) who studied 12 to 23 year olds not only found that the tendency towards eveningness was positively related to pubertal maturation and age, but there was a shift back towards the morningness chronotype around the age of 21. Roenneberg et al. (2004) considered the shift back toward morningness around the age of 20 to be considered "a biological marker for the end of adolescence" (p. R1039), and that adulthood begins when a person's chronotype begins advancing towards morningness rather than delaying towards eveningness. Before around the age of 20, Roenneberg et al. (2004) also found that chronotypes delay with increasing development and age.

Hagenauer, Perryman, Lee, and Carskadon (2009) found that circadian phase delay not only occurs in humans but occurs in a variety of mammalian species during puberty. They reviewed and analyzed the data from nine studies conducted by different researchers that studied the circadian rhythms of different animal species. They found that all species studied, which included a laboratory rat, rhesus monkey, degu, fat sand rat, and a laboratory mouse all exhibited the same circadian phase delay that occurs in human adolescents that began around the onset of puberty. These findings further strengthen the notion that the tendency for adolescents to go to bed later is a result of biological changes that occur during puberty.

Carskadon, Acebo, Richardson, Tate, and Siefer (1997) developed a sleep procedure to study the phases of the circadian rhythms of adolescents more accurately. Called the “long nights” protocol, Carskadon et al. (1997) studied 11 to 14 year olds under strict sleep conditions that controlled for the amount of light and dark, and prevented environmental factors from interfering with the adolescents’ sleep schedules. While the researchers did not find a significant relationship between puberty stage and melatonin secretion onset, they did find a significant relationship between puberty stage and melatonin offset, meaning those adolescents who were more pubescent stopped producing melatonin later into the early morning.

Carskadon, Wolfson, Acebo, Tzischinsky, and Siefer (1998) argued that the social demand of earlier school start times for adolescents is in point blank conflict with the pubertal phase delay that adolescents experience. They proposed that transitioning to an earlier high school start time while biologically experiencing a phase delay would cause adolescents to obtain less sleep and exhibit more sleepiness during the day. Given an early school start time, such adolescents would have to go to bed at an unrealistic and infeasible bedtime to obtain enough sleep and avoid sleepiness the next day. Regarding wake up times, Carrell, Maghakian, and West (2011) explained that because melatonin production for adolescents is at its peak until 7:00 am compared to 4:00 am for adults, "waking up a teenager at 7 AM is equivalent to waking up an adult at 4 AM" (p. 64).

Over the course of two school years, Carskadon et al. (1998) studied 40 adolescents when they were in the ninth grade and in the 10th grade. The significance of these adolescents was that in ninth grade, they had a middle school start time of 8:25 am, but in 10th grade, they transitioned to a high school where the school start time was 65 minutes earlier at 7:20 am. One would expect that with an earlier school start time, adolescents would go to bed earlier to make up for an earlier rise time. The researchers found this not to be the case. The students' school night sleep patterns (including sleep onset time and sleep offset time) were examined while they were in their home setting for two weeks. After that, the students' sleep was studied in a lab setting while they were constrained to the same sleep schedule they held at home on the school nights in the previous two weeks. The researchers found that while the 10th graders had an earlier school start time, their sleep onset time was not significantly different than when they were in ninth grade, but their sleep offset time was earlier, meaning the 10th graders obtained less sleep each night. Also, on average, the melatonin secretion onset for the 10th graders was 40 minutes later than when they were in ninth grade. Even though they experienced an earlier school start time and therefore an earlier wake time, melatonin secretion began later in the night for the 10th graders compared to the ninth graders.

What is the most surprising about the findings of this study conducted by Carskadon and her colleagues is the short sleep latency and the occurrence of REM sleep during unexpected times for the adolescents. Besides being studied at night in their sleep, the adolescents were also administered the multiple sleep latency test (MSLT) four different times throughout the daytime (twice in the morning and twice in the afternoon). Carskadon et al. (1986) as cited in Carskadon et al. (1998) indicated that the MSLT measures an individual's sleep propensity through measuring the time it takes to fall asleep. The researchers found that when given the MSLT, the sleep latency for the 10th graders was shortest during the 8:30 am MSLT test, which was the time when they would be attending their second period class of the school day. Over a third of the 10th graders experienced an average sleep latency of less than six minutes; the shortest sleep latency time was 1.8 minutes! Four students when in the ninth grade and 12 of the students when in the 10th grade experienced REM sleep on the MSLT, with most all these REM episodes occurring in the morning administrations of the MSLT. Experiencing REM sleep on the MSLT is often a sign of narcolepsy, yet no student being studied had a history of narcolepsy. Carskadon et al. (1998) pointed out that if the students that experienced REM sleep on the MSLT exhibited the same sleep patterns in the non-laboratory setting, then they would be waking up on school days during times when their circadian rhythms encouraged REM sleep, with this encouragement lasting many hours after their wake time. The short sleep latency times and the occurrence of REM sleep during times when the students would be in their morning classes is indicative of just how sleepy they are.

Synchrony Effect

Since science proves that adolescents are biologically predisposed to a circadian rhythm that promotes an evening chronotype, it is important to take note of the potential impact this may have on their performance in school. The term "synchrony effect" refers to the observation that people perform best when they are tested during their optimal arousal times (May & Hasher, 1998). In simpler terms, an adolescent with an evening chronotype would therefore perform better on a test administered later in the day rather than in the morning. While this synchrony effect does not appear to impact the examinees' retrieval and use of semantic knowledge during testing, May and Hasher (1998) found that the time of testing affects cognitive inhibition. They found that test subjects were less able to inhibit irrelevant information when tested during times that did not match their optimal arousal time, and they were better able to control such information when tested during times that matched their chronotype.

The findings of May (1999) further corroborate the findings of May and Hasher (1998). Very similarly to the aforementioned findings, May found that when people are tested during times that are not optimal for them based on their chronotype, the examinees are less able to inhibit irrelevant information and are more susceptible to off-task distractions. As a result, May (1999) recommended:

> Because suppression of off-task distractors will be particularly difficult at off-peak times, complex tasks that require focused attention (e.g., reading complex instructions), retrieval of exact information (e.g., recalling medication dosages),

> or careful control over responses (e.g., driving in heavy traffic) should be completed at peak hours or in a setting in which distractions are kept to a minimum (p. 146).

Despite this recommendation, adolescents whose peak arousal time is not in the morning but in the late afternoon or evening are still expected to take early morning exams in school.

The findings of Hansen, Janssen, Schiff, Zee and Dubocovich (2005) support the notion of the synchrony effect. All the students in their study performed better on vigilance tests and felt more vigorous in the afternoon compared to the morning. Because the morning is when students perform the poorest, the researchers proposed that standardized tests should be given at 10:00 am, compared to earlier in the morning at 8:00 am. A report published by Wahlstrom et al. (2014) found that the majority of the high school students they surveyed, roughly 60%, felt 11:00 am to 1:00 pm would be the optimal time for them to take a test.

Goldstein, Hahn, Hasher, Wiprzycka, and Zelazo (2007) observed the impact of the synchrony effect on something as concrete as IQ scores. They administered the Wechsler Intelligence Scale for Children-III (WISC-III) to 11 to 14 year olds during times that coincided more with their chronotype and during times that coincided less with their chronotype. The testing times were 8:00 to 10:00 am and 1:00 to 3:00 pm, to reflect times found within an average school day schedule. Not surprisingly, the adolescents tested during their preferred time of day based on their chronotype outperformed the adolescents who were tested during times that differed from their time of day preference, with those tested during their optimal times earning a six-point higher Full Scale IQ score. Again, while this synchrony effect did not apply to semantic knowledge (in this case crystallized intelligence), the synchrony effect did apply to fluid intelligence. Goldstein et al. (2007) noted that the six-point difference in IQ scores caused by the synchrony effect they observed is something that could have serious implications for students close to qualifying for special education services or gifted and talented services in school.

Environmental Factors

While biological processes that occur during puberty impact adolescent sleep patterns in a major way, one cannot ignore the impact the emergence of certain environmental factors also plays on adolescent sleep. Such environmental factors discussed here are changes in parental influence, caffeine use among adolescents, adolescent employment, and electronic device use before bed. Another possible environmental factor that will not be discussed is extracurricular activities.

Parental influence. As children grow older, their parents tend to have less influence over their bedtimes, which impacts how much sleep they may receive. The National Sleep Foundation (2006) in their *2006 Sleep in America Poll* found that from sixth grade to 12th grade, the percentage of adolescents having a set bedtime created by parents decreased, with 95% of sixth graders having a set bedtime, but only 39% of 12th graders having a set bedtime. For those older adolescents in the ninth to 12th grade who did have a set bedtime created by parents, the majority had a bedtime of 10:00 pm or later. This study found that those adolescents who did not have a set bedtime created by parents or who had a set bedtime after 10:00 pm were more likely to receive insufficient school night sleep and were less likely to report having a good night's sleep.

Similarly, when studying 385 adolescents in Australia, Short et al. (2011) also found that the percentage of adolescents with a bedtime set by parents decreases with increased adolescent age. Although the adolescents who had a bedtime set by parents were in the minority for the whole population of the study, they went to bed earlier on school nights, received on average 19 more minutes of sleep, reported being less tired during the day, and were more capable of maintaining wakefulness during activities throughout the day compared to the majority group in the study who did not have bedtimes set by parents. While the researchers pointed out that 19 more minutes of sleep may seem inconsequential, it can have a cumulative effect on positive daily functioning. They also noted that because there are many factors that delay adolescent bedtimes and shorten their sleep duration, parental influence on bedtimes can be one thing to hinder these factors. Unfortunately, however, parents setting bedtimes for their teenagers appear to be in the minority.

Bedtime rules set by parents are not the only form of parental influence that affects adolescent sleep amount. The National Sleep Foundation (2014) in their *2014 Sleep in America Poll, Sleep in the Modern Family* survey found that parental rules on how late their children could watch television, play video games, be on their cell phone, and be on their computer, and rules about caffeine consumption in the afternoon and evening can positively impact the sleep duration of their children. Unfortunately, however, the study found that the occurrence of such rules enforced by parents decreases with age, with the 15 to 17 year olds in the study much less likely to have the aforementioned rules enforced by parents than their younger aged counterparts. When compared to adolescents whose parents did not set night time rules, adolescents received

1.1 more hours of sleep when their parents set rules for bedtime, they received .7 more hours of sleep when their parents set rules about caffeine consumption, they received .6 more hours of sleep when their parents set rules about nighttime television watching, they received .3 more hours of sleep when their parents set rules about nighttime cell phone use, and they received .5 more hours of sleep when their parents set rules about nighttime video game and computer use. Because most older adolescents do not have such rules enforced by parents, it can be assumed they do not reap the benefits of a longer sleep duration that the rules provide.

Caffeine consumption. Just as lack of parental influence is prevalent during the adolescent years, so too is caffeine consumption amongst teenagers. The National Sleep Foundation (2006) found that 75% of adolescents drink at least one beverage containing caffeine in a day and 31% of adolescents drink two or more beverages containing caffeine in a day. The adolescents who drink two or more caffeinated beverages per day are more likely to get less sleep than needed on a school night and are more likely to report getting a poor night's sleep.

In a study of 15,686 sixth to 10th graders, Orbeta, Overpeck, Ramcharran, Kogan, and Ledsky (2006) found that the majority of the students polled drank one or more caffeinated sodas per day and the students classified as having a high caffeine intake were nearly two times more likely to have trouble sleeping at night and to be more tired in the morning. Pollak and Bright (2003) found that increased caffeine consumption amongst 12 to 15 year olds was associated with a decreased sleep duration at night and an increased WASO (wake time after sleep onset), which measures periods of wakefulness after falling asleep. Lastly, Wright, Badia, Myers, Plenzler, and Hakel (1997) found that caffeine consumption before bed can repress melatonin levels. They found that in a laboratory low light setting, when compared to the melatonin levels of someone not consuming caffeine, the repression of melatonin in someone consuming caffeine is comparable to the repression of melatonin in someone spending the night in a bright light setting.

Adolescent employment. As of 2019, 30.9% of 16 to 19 year olds were employed (U.S. Bureau of Labor Statistics, 2019). The National Sleep Foundation (2006) found that adolescents working over ten hours a week are more likely to get insufficient sleep. Wolfson (2001) explained that adolescents working more than 20 hours per week may encounter negative consequences such as missing school, earning poor grades, and falling asleep while driving due to the insufficient sleep they experience from working. They may exhibit extreme sleepiness during the day, diminished alertness, and may be more prone to risky behaviors.

Summarizing the previously unreported findings of a 1994 study of 3,120 Rhode Island students (see Wolfson and Carskadon, 1998), Wolfson (2001) reported that 52% of the 11th and 12th graders were employed and 56% of those employed were working 20 or more hours per week. These students that worked 20 or more hours per week had later school night bedtimes and obtained less school night sleep, obtaining an average sleep duration of six hours and 57 minutes. They also reported more daytime sleepiness.

Electronic use. When discussing environmental constraints on adolescent sleep, one cannot ignore the overwhelming role electronics has come to play in the lives of adolescents. The National Sleep Foundation (2006) found that 97% of 11 to 17 year olds have at least one electronic device in their bedrooms and the number of electronic devices increases with age, with the median number of devices in the bedroom for 12th graders being four. Likewise, the National Sleep Foundation (2014) also found that the existence of electronics in the bedroom and the number of electronics in the bedroom is positively associated with an adolescent's age. Such electronics in the bedroom include televisions, video game consoles, computers, tablets/smart phones, and music players. This study reported that while 72% of children ages six to 17 have at least one electronic device in their room, 89% of 15 to 17 year olds have at least one electronic device in their room. The median number of electronics that six to 11 year olds have in their room is one while the median number of electronics 15 to 17 years olds have in their room is three.

A comprehensive report published by Wahlstrom et al. (2014) comprising the survey results of 9,089 high school students from five school districts across three states found similar trends to the National Sleep Foundation polls. Roughly 88% surveyed had a phone in their bedroom and 41% had a computer in their bedroom. The presence of these electronic devices in the bedroom was significantly related to sleep duration. The adolescents with these electronic devices in their bedroom were less likely to obtain more than eight hours of sleep per night compared to students without these electronic devices in their bedroom. Similarly, Titova et al. (2015) found that adolescents who peruse the internet at night have more sleep disruptions throughout the night compared to adolescents who do not use the internet at night.

The use of electronic devices by adolescents right before bed on school nights and keeping electronic devices on during the night is prevalent. The National Sleep Foundation (2011) in their *2011 Sleep in America Poll, Communications Technology in the Bedroom* survey found that on an average night, within the hour before going to bed, 72% of 13 to 18 year olds go on their cell phones, 56% engage in text messaging, 60% go on their computers, 23% play video games, 54% watch television, and 64% use music players. This poll found that 28% of the teenagers surveyed sleep with their cell phone ringers on, resulting in 18% of them being aroused from their sleep in the night at least a few nights per week. In their study of 12 to 18 year olds to assess the impact of caffeine use and electronic use on sleep, Calamaro, Mason, and Ratcliffe (2009) found that after 9:00 pm, among the adolescents in their study, 86.4% with televisions in their bedroom watched television, 34% engaged in text messaging, 44% talked on the phone, 55% went on the internet, and 24% played computer games. The adolescents were engaged in these activities for an average of one to two hours. The National Sleep Foundation (2014) found that 39% of the respondents in the study sometimes leave their television on at night, 14% sometimes leave their computer on at night, 35% sometimes leave their smartphone/tablet on at night, 11% sometimes leave their video games on at night, and 37% sometimes leave their music player on at night. The sleep duration for the respondents who left their electronic devices on at night was significantly shorter than those who turned their devices off.

To summarize the findings of the extensive body of literature in existence on the topic of electronic use and sleep, Hale and Guan (2015) conducted a meta-analysis of 67 studies completed around the world between 1999 and 2014 that examined electronic use and sleep amongst five to 17 year olds. Seventy-six percent of the studies analyzed involving television use found a negative association between television use and sleep, with 25 of those studies finding a significant relationship between television watching and later bedtimes or shortened sleep duration. Ninety-four percent of the studies analyzed involving computer use found a negative relationship between using the computer and sleep, with 24 of the studies finding a negative relationship between computer use and sleep duration. Eighty-six percent of the studies analyzed involving video game use found a negative association between playing video games and sleep, with 13 studies finding a significant relationship between video game use and later bedtimes or shortened sleep duration. Lastly, 83% of the studies involving cell phone use found a negative association between cell phone use and sleep, with 10 studies finding a significant relationship between cell phone use and later bedtimes or shortened sleep duration.

Overall, Hale and Guan (2015) found that 90% of the total studies they analyzed found a significant relationship between electronic screen time and at least one type of sleep problem, whether that be later bedtimes, shortened sleep durations, poorer sleep quality, or daytime tiredness. They also found that in many of these studies, the older adolescents were more apt to experience the negative relationship between electronic use and sleep. While Hale and Guan pointed out that even though the studies provided enough data to build significant relationships between electronic screen time and sleep problems, none of the studies provided enough data to build causal relationships between the two. Nevertheless, they pointed out that the importance of staying up to date on the consequences of electronic use on sleep in an age in which electronic devices are being rapidly adopted by society.

Despite the studies analyzed by Hale and Guan (2015) not providing enough data to develop causal relationships between electronic screen use and sleep problems, there is evidence of electronic screen use influencing biological mechanisms that impact sleep.

Two almost identical studies required participants to engage in reading print material before bed for five successive nights and then engage in electronic tablet use before bed for five successive nights in a laboratory setting. Both studies found that on the fifth night of electronic tablet use, compared to the fifth night of print material use, the onset of melatonin secretion was delayed and suppressed, sleep latency took longer, and participants were less sleepy and more alert before bed but more sleepy upon waking in the morning (Chang, Aeschbach, Duffy, & Czeisler, 2015; Chinoy, Duffy, & Czeisler, 2018). Furthermore, Chang et al. (2015) found that in the tablet use nights, participants obtained much less REM sleep and Chinoy et al. (2018), whose study allowed participants to select their own bedtimes, found that participants went to bed much later on the tablet use nights compared to the print material use nights. Wood, Rea, Plitnick, and Figuerio (2013), who had participants engage in whatever task they wanted to on Apple iPads from 11:00 pm to 1:00 am, found that being on the iPads for two hours significantly suppressed melatonin levels in the participants.

Sleep Patterns

After discussing the biological and environmental factors that significantly impede adolescent sleep, what exactly does adolescent sleep look like? In summary, Carskadon (1999) explained that overall, while the sleep requirements do not change for adolescents, they go to bed later and wake up later than their younger counterparts when given the chance. Adolescents tend to obtain less sleep as they get older, have more sleepiness during the day, and obtain more sleep on weekends versus weekdays. Wahlstrom et al. (2014) found that the main reason adolescents go to bed at a specific time on both school nights and weekend nights is because they feel sleepy, and the main reason they wake up at a specific time on school mornings is because their alarm clock wakes them up. This is a sign that, in general, adolescents go to bed when they feel biologically inclined to, but they are not allowed to wake up naturally on school mornings.

Despite the recommendations provided by professional organizations on the sleep amount for adolescents, the National Sleep Foundation (2006) found that while 45% of all adolescents in grades six to 12 obtain less than eight hours of sleep each night, which is an inadequate amount, 62% of ninth to 12th graders obtain an inadequate amount of sleep. On an average school day, 60% of sixth to eighth graders go to sleep before 10:00 pm, 43% of ninth to 12th graders go to sleep between 10:00 pm and 11:00 pm, and 38% of ninth to 12th graders go to sleep after 11:00 pm, with 54% of 12th graders going to bed after 11:00 pm.

On days when there is not school and not the constraint of school start times, the National Sleep Foundation (2006) found that adolescents obtain more sleep. On non-school days, sixth to eighth graders obtain .8 to .9 more hours of sleep on average and ninth to 12th graders obtain 1.2 to 1.9 more hours of sleep on average. On weekends, sixth to eighth graders typically go to bed between 10:30 pm and 11:30 pm and wake up around 9:00 am, while ninth to 12th graders typically go to bed after midnight and wake up around 10:00 am. These figures prove the tendency for adolescents to go to bed later, want to wake up later, and obtain less sleep as they get older.

Noland, Price, Dake, and Telljohann (2009) surveyed high school students in three schools in the Midwest to determine their sleep patterns and perceptions of sleep. Of those surveyed, 73.3% felt that students in high school should be receiving eight to nine hours of sleep on school nights. Despite this, 66.8% of respondents reported receiving fewer than eight hours of sleep on school nights, and only five percent of respondents reported getting more than nine hours of sleep on school nights. In addition, similar to previously reported data, the researchers found that the majority of respondents obtained much more sleep on the weekends and were much more likely to receive the recommended amount of sleep on weekends.

School Start Times

One environmental factor that was not previously addressed which has a significant impact on adolescent sleep duration is school start time. With the overwhelming evidence proving that adolescents are susceptible to insufficient sleep because of the emergence of biological and environmental factors, is it reasonable that school districts are implementing school start times that further exacerbate adolescent sleep problems? Likewise, given the science behind the synchrony effect and the research indicating that adolescents tend to shift to an evening chronotype, is it reasonable that because of early school start times, school districts are having adolescents perform academic tasks during times that do not align with their optimal performance times? Earlier school start times, as demonstrated through the ensuing summarized research, have been linked to shorter sleep durations and lower academic performance.

Impact on Sleep Duration

Multiple studies have found an association between delayed school start times and longer sleep durations for adolescents. Wheaton, Chapman, and Croft (2016) conducted a literature review of studies involving the relationship between school start times and sleep duration, among other sleep outcomes. After using PubMed to conduct a specific search using the search term "school start time" or "school start times" and a broader search using the search terms "sleep", "adolescents", and "school", Wheaton, Chapman, and Croft narrowed 3200 studies down to 38 studies that followed the inclusion criteria of only including middle school or high school students and being a cross sectional or longitudinal analysis that included school start time as a variable.

Of the 38 studies reviewed by Wheaton et al. (2016), 29 of the studies found a positive association between later school start times and sleep duration on weekdays, primarily through the mechanism of adolescents waking up later in the morning. This was even true for the studies that found that adolescent bedtimes became later with later school start times. Even though students in six studies went to bed later because of later school start times, they still obtained more sleep when compared to students having earlier school start times. Even though most of the studies reviewed by Wheaton, Chapman and Croft relied on self-reported data from the adolescents being studied, the two studies which utilized actigraphy rather than self-reported data did confirm the positive association between school start times and sleep duration. Another observation noted by the researchers was, of the studies that reported on the sleep patterns of adolescents over the weekend, seven studies found that adolescents engaged in more weekend "catch-up" sleep when they had earlier school start times. Also, 11 of the 29 studies which found a positive association between school start times and sleep duration, found that every two-minute delay in school start time led to one more minute of sleep duration.

Minges and Redeker (2016), Morgenthaler et al. (2016), and Bowers and Moyer (2017) also drew interesting conclusions after conducting other literature reviews on delayed school start times and sleep duration. After narrowing 818 articles down to six articles which contained their inclusion criteria, Minges and Redecker (2016) observed that while the studies they were examining reported on school start time delays ranging from 25 to 60 minutes, the increase in sleep duration noted in the studies ranged from 25 to 77 minutes of sleep per school night. Morgenthaler et al. (2016) narrowed 287 studies down to 18 studies, eight of which they conducted a meta-analysis on. They determined that of the studies that reported on a delay in school start time of 60 minutes or less, the sleep duration for adolescents increased by an average of 18.65 minutes, and among the studies that reported on a delay in school start time longer than 60 minutes, the sleep duration increased by 52.56 minutes. Bowers and Moyer (2017), conducted meta-analyses on five longitudinal studies and 15 cross-sectional studies that all examined the impact of school start time delays on sleep duration. Their meta-analyses revealed that positive associations existed between delayed school start times and sleep duration for all studies.

Meltzer, Shaheed, and Ambler (2014) sought to take a different approach to examining the impact of school start times on sleep duration by being the first researchers to compare the sleep duration of public/private school students to homeschooled students. Using homeschooled students as a comparison group makes sense because homeschooled students are not constrained by early school start times and do not have to wake up earlier to catch a school bus. The researchers had a homeschooled student group and public/private school student group, with both groups matching on demographics, complete the same survey used by the National Sleep Foundation in 2006.

Not surprisingly, Meltzer et al. (2014) found that public/private school students obtained much less sleep during the school week than the homeschooled students. Even though the homeschooled students were found to have school night bedtimes on average 39 minutes later than the public/private school students, the public/private school students were found to wake up 85 minutes before the homeschooled students. In this study, the mean school start time for the homeschooled students was 9:00 am while the mean school start time for the public/private school students was 7:56 am. Homeschooled students woke up at about the time the school day was starting for the public/private school students. This difference in morning wake times between the two groups of students accounted for public/private school students obtaining four fewer hours of sleep over the course of one school week when compared to the homeschooled students. Other notable differences between the two groups of students were that public/private school students overslept more on the weekend when compared to the amount of their weekday sleep, public/private school students were more apt to take naps during the week compared to homeschooled students, and while 58% of homeschooled students obtained sufficient sleep on school nights, only 28.2% of public/private school students obtained sufficient sleep on school nights.

Also, to further assess the impact of school start times on sleep duration, Meltzer et al. (2014) broke school start times into four different categories (before 8:00 am, 8:00 to 8:30 am, 8:31 to 9:00 am, and after 9:00 am). They observed that while students had later bedtimes with later school start times, the wake times for all students were much later for each school start time category. To clarify, students obtained 25 more minutes of sleep when they started school between 8:00 and 8:30 when compared to before 8:00, and students obtained 26 more minutes of sleep when they started school between 8:31 and 9:00 when compared to between 8:00 and 8:30.

A limitation to many of the studies addressed in this section is that they rely on student self-reported data through surveys, polls, and questionnaires which may not always depict adolescent sleep patterns the most objectively. Fortunately, the studies that make use of actigraphy data, confirm the findings of the studies that used self-reported data. As explained earlier, the longitudinal study using actigraphy data conducted by Carskadon et al. (1998) found that school night sleep duration was about 20 minutes longer when the students were in ninth grade compared to 10th grade, when the ninth grade school start time was 8:25 am compared to the 10th grade start time of 7:20 am.

Dunster et al. (2018) used actigraphy data in a pretest/posttest study when the Seattle School District delayed high school start times from 7:50 am to 8:45 am from one year to the next. After gathering actigraphy data from sophomores in the spring of 2016 and the spring of 2017, with the two school years separated by the later school start time, the researchers found that students in 2017 had a median wake up time of 44 minutes later compared to 2016. The students in 2017 also had a median sleep duration of 34 minutes longer compared to 2016.

Lastly, amongst the studies reviewed using actigraphy data, Nahmod et al. (2019) used 14 to 17 year olds from the longitudinal across country *Fragile Families and Child Wellbeing Study* to collect actigraphy data on sleep while the participants all had different school start times. This large study resulted in 383 adolescents who took part and contained actigraphy sleep data from 1116 school nights. Because the participants all had different school start times, the researchers broke the school start times into four categories: before 7:30 am, 7:30 am to 7:59 am, 8:00 am to 8:29 am, and 8:30 am or later. Analyses and observations by the researchers determined that while the students starting school at 8:30 am or later went to bed later than those starting school before 7:30 am, they still obtained more nighttime sleep than those starting school before 7:30 am as a result of much later wake times. The students starting school during the three latest school start time categories woke up 32 to 64 minutes later than those attending school before 7:30 am, which resulted in the later starting students obtaining 21 to 34 more minutes of sleep each day.

Nahmod et al. (2019) determined through their analyses that for a one-hour delay in school start time, wake up time becomes 39 minutes later, and sleep duration becomes 21 minutes longer. However, the researchers pointed out that despite these results, the students starting school at 8:30 am or later still only achieved an average sleep duration of 7.6 hours of sleep per night, which is still less than the recommendation provided by the National Sleep Foundation. Despite this, school districts should still place an emphasis on doing everything in their power to help students obtain as much sleep as possible.

Another limitation to many of the studies addressing school start times and adolescent sleep duration is that they focus on older adolescents attending high school even though younger adolescents in middle school often must contend with early school start times as well. The studies by Lewin et al. (2017) and Wolfson, Spaulding, Dandrow, and Baroni (2007) focused solely on middle school students and the results of these studies are similar to those studying high school students. Lewin and his colleagues examined the self-reported sleep patterns of a total of 26,440 eighth grade students comprising three different graduating classes in one diverse school district where school start times ranged from 7:20 am to 8:10 am. Like aforementioned studies examining high school students, the researchers found that the eighth graders who had a later school start time (8:00 am to 8:10 am) were more likely to report a longer sleep duration, and a later school start time was associated with an increased probability of obtaining optimal sleep. The probability of receiving the recommended amount of sleep for the eighth graders with school start times of 7:40 am to 7:50 am was 74%, and it was only 31% for eighth graders with school start times of 7:20 am to 7:30 am.

Wolfson et al. (2007) examined the sleep patterns of seventh and eighth grade students attending two demographically similar middle schools within the same school district after the school district implemented new school start times the summer before. One school had a new school start time of 7:15 am while the other had a new start time of 8:37 am. As expected, the students attending the school with the later start time obtained much more sleep each night due to later rise times, were less sleepy during the day, and were more apt to obtain more than nine hours of sleep each night. Thirty-seven percent of students attending the late starting school obtained more than nine hours of sleep per night while only 18% of students attending the early starting school obtained more than nine hours of sleep per night.

To determine whether the same sleep patterns of the middle school students endured throughout the school year, Wolfson et al. (2007) conducted analyses for their study six months apart in the fall and in the spring of the same school year. They found that in the fall, even though the students attending the late starting school went to bed later, they obtained 37 more minutes of sleep due to waking up an hour and 15 minutes later and leaving for school an hour and a half later. In the spring, the difference in total sleep time between students attending the two different schools increased to 65 minutes, due in large part to a decrease in the amount of sleep received by the students attending the school with the early start time. The sleep duration of the students attending the school with the later start time did not significantly change from the fall to the spring.

Further studies strengthen the argument that school start times are associated with sleep duration. While not looking at specific school start times per se, Hansen et al. (2005) found that high school students lose up to 120 minutes of sleep per weeknight once they start attending school in the fall, compared to summer weeknights. Boergers, Gable, and Owens (2014) found that during an experimental boarding school start time change in which school start times were delayed from 8:00 am to 8:25 am and then switched back to 8:00 am throughout one school year, sleep duration increased by 29 minutes with the delayed start time, but then reverted back to baseline when the start time was changed back to 8:00 am. They also found that the number of students receiving more than eight hours of sleep per school night more than doubled with the later start time. Wahlstrom et al. (2014) found that adolescents attending high schools with start times before 8:35 am obtained, on average, 7.8 hours of sleep on school nights, whereas adolescents attending the high school with a 8:55 am start time obtained, on average, more than eight hours of sleep per school night. Lastly, Wahlstrom (2002) found that students attending a high school with an 8:40 am start obtained roughly one more hour of sleep per school night compared to demographically alike students attending a high school with a 7:30 am start, despite both groups of students going to bed around the same time. This difference in sleep durations persisted four years later.

Counterarguments. Despite the data from the reviewed studies confirming that later school start times are associated with longer sleep durations amongst adolescents, conflicting observations made by three studies should be noted. Studies conducted by Rhie and Chae (2018) and Thacher and Onyper (2016) found that the longer sleep durations experienced by students during a transition to later school start times was not long lasting, These studies observed that students' sleep durations eventually returned to the same levels as before the implementation of the delayed school start times. A study by Parksarian, Rudolph, He, and Merikangas (2015) observed a plateau effect regarding school start times and sleep duration.

The large scale study conducted by Rhie and Chae (2018) in South Korea which included 42,517 students in the intervention group and 28,287 students in the control group, sought to determine the impact on sleep duration when the middle schools of the students in the intervention group were delayed one half hour to one hour and when the high schools of the students in the intervention group were delayed one hour to one and a half hours. This study found that while the sleep duration amongst adolescents in the intervention group temporarily increased as a result of later wake times, their sleep duration reverted to pre-campaign levels shortly thereafter because of a simultaneous delay in sleep onset times. Despite this data, however, the study did find that the students in the intervention group decreased the difference between their weekday sleep duration and their weekend sleep duration compared to the control group, which the researchers see as a sign of less sleepiness amongst the intervention group.

In their study, Thacher and Onyper (2016) pointed out that there is limited knowledge of whether the first observed benefits of a delayed school start time continue long after. Their longitudinal study conducted in an upstate New York high school analyzed the sleep data provided through questionnaires given to students during a transition to a later school start time, from 7:45 am to 8:30 am. The questionnaires were given to students at three different times: in May of 2012 before the school start time change, in November of 2012 after the school start time change, and in May of 2013, one year after the school start time change. What the researchers found out was while sleep duration did increase by 20 minutes as of November 2012 due to delayed wake times and fixed bedtimes, the sleep duration for the majority of students returned to baseline levels as of May 2013 due to a consequent delay in bedtimes.

Despite the data predominantly indicating a return to the baseline sleep duration after one year, Thacher and Onyper found that 10% of the students in the study did continue to experience an increase in sleep duration one year after the school start time change. These students were the ones who were more apt to experience less sleep before the school start time change and who identified as having an evening chronotype. Given their findings, the researchers wrote in the conclusion of their study:

> Although a start time delay is the first—and necessary—step to improved sleep health, clearly a delay in start time alone may not be sufficient to achieve the kinds of changes to student performance and well-being that are the targets for changes to school schedules (Thacher and Onyper, 2016, p. 280).

One limitation important to note about the aforementioned study is all students attending the school in the study lived within walking distance of the school and no school bussing was used. Therefore, the wake times of students were not confined by school bus pick up times.

The studies conducted by Thacher and Onyper (2016), Rhie and Chae (2018), and Wolfson et al. (2007) all took a longitudinal approach and analyzed adolescent sleep data at two different points in time to determine whether the sleep patterns surrounding a school start time change persisted months after the first data analysis. While the former studies found that the initial effects of new later school start times were not long lasting, the latter study found that sleep durations continued to be the same for the students attending the later starting school compared to the earlier starting school. A few differences between these studies should be noted that may potentially account for the difference in results. First, the studies by Thacher and Onyper (2016) and Rhie and Chae (2018) examined high school students (in addition to middle school students for the Rhie and Chae study) while the study by Wolfson et al. (2007) solely examined middle school students. The data analyses of the two former studies were conducted a full year apart, while the data analyses of the latter study were conducted roughly six months apart, within the same school year. Lastly, what should especially be noted for the Rhie and Chae study is it was a large scale study conducted over five years which comprised tens of thousands of students, and it had an experimental design composed of a control group and an intervention group. Rhie and Chae (2018) called it a “5-year prospective case-controlled cohort study” (p. 6).

While examining how the association between school start times and sleep patterns differ based on demographic factors such as age, sex, and geographic location of the students (urban vs. nonurban), Paksarian et al. (2015) found a plateau effect regarding such associations. By using data from the cross-sectional *National Comorbidity Survey—Adolescent Supplement*, the researchers were able to analyze the sleep duration data of

7216 adolescents representing a variety of demographics across the U.S. While using exploratory analyses, the researchers found that a positive association between sleep duration and school start times existed only with school start times before 8:01 am. The association became insignificant with school start times after 8:01 am. The same held true for the relationship between the odds of getting enough school night sleep and school start times. Before 8:01 am, the odds of getting enough sleep was positively associated with school start times, but the association again became insignificant with school start times after 8:01 am.

One thing Paksarian et al. (2015) found through their regression models that is interesting to note is that when controlling for all other factors, no significant association was found between sleep duration and school start times before or after 8:01 am for females. They actually found a negative association existed between school start times and sleep duration for males living in rural counties, when controlling for all other factors. Ultimately, Paksarian and her colleagues determined that the strongest association between sleep duration and school start times existed for males attending schools in large metropolitan areas.

Given their findings that the strength of the association between school start times and sleep duration differs based on the demographics of the students and that the strength of such associations plateaus in many instances, Paksarian et al. (2015) drew multiple conclusions. First, they concluded that “a single start time recommendation may not be appropriate in all contexts, and they [their findings] highlight the need to consider other contextual, family, and individual factors that may modify associations between school start time and sleep” (Paksarian et al., 2015, p. 1355). An example of one such factor that may affect the association is transportation mode to school, which may differ between urban and rural school settings. Secondly, given the found plateau effect, the researchers suggested that delaying school start times very modestly may be adequate to maximize any related benefits to adolescent sleep duration. Lastly, Paksarian and her colleagues iterated the need for more research to determine under which contextual and demographic factors a delayed school start time would be most beneficial for adolescent sleep duration.

Sleep Duration and Academic Performance

The research summarized in the earlier sections show that, with some caveats attached, early school start times, along with biological and other environmental factors shorten the sleep durations of adolescents. However, it is important to understand the potential impact a shorter sleep duration can have on the academic performance of adolescents. An extensive body of research exists, including studies cited previously, which examine the possible link between sleep duration and academic performance.

Dewald, Meijer, Oort, Kerkhof, and Bögels (2010) conducted a meta-analysis to determine the effect size that the sleep variables of sleep duration, sleep quality, and daytime sleepiness have on academic performance. The researchers conducted a separate meta-analysis for each sleep variable and measured school performance in terms of student and parent answered surveys, grade point average, and standardized test scores. The studies included in the meta-analysis were ones in which the participants were aged eight to 18 and excluded studies in which participants had sleep disorders, mental illnesses, or physical illnesses. Most of the studies were also cross-sectional rather than longitudinal. Overall, 16 studies were used assessing the impact of sleep quality on school performance and 17 studies were each used for assessing the impact of sleep duration and daytime sleepiness on school performance.

Overall, through their meta-analyses, Dewald et al. (2010) found an association between each sleep variable studied and school performance, but with each sleep variable having a different effect size on school performance. While the effect sizes were statistically significant, they were quite modest. Daytime sleepiness had the largest effect on school performance, sleep quality had the second largest effect on school performance, and sleep duration had the smallest effect on school performance. Regardless of the effect size for each sleep variable, all three were still significantly significant. An interesting observation pointed out by Dewald and her colleagues, is that the larger effect sizes were found in the studies using younger participants, causing the researchers to assume that poor sleep and more sleepiness has a larger impact on the prefrontal cortex and cognitive functions in early adolescence. Given the modest effect sizes they found, the researchers concluded by stressing the need for more research using longitudinal and experimental designs to better establish the relationship between sleep and school performance.

A study conducted by Wolfson and Carskadon (1998) which used the survey results of 3,120 adolescents attending four Rhode Island high schools found a link between school grades and sleep duration. By analyzing the students' answers to the *School Sleep Habits Survey*, Wolfson and Carskadon found that the students who obtained A's and B's for grades reported a longer sleep duration and earlier bedtimes on school nights compared to the students who obtained mostly C's, D's, and F's. Likewise, those students reporting better grades had more consistent sleep schedules from the school nights to the weekends. Those reporting poorer grades went to bed much later on weekends and slept in much later on weekends compared to students earning A's and B's. As explained by the researchers, students who obtain more sleep may earn better grades by being better able to pay attention to class instruction and on homework. Wolfson and Carskadon (1998) concluded their study emphasizing the need for schools to explore the connections between sleep and aspects of academic functioning such as test scores and grades.

Like the findings of Wolfson and Carskadon, Cole (2016) found a link between self-reported sleep duration and grades. However, he also examined the potential role sleep duration may have on ACT and SAT scores and found a surprising result. Cole used survey results from 13,071 college freshmen who completed the *Beginning College Survey of Student Engagement* (BCSSE), which asked students about their grades, study habits, sleep habits, and SAT and ACT scores from their later years in high school. He found that the students who woke up later in the morning obtained the most sleep, and the students who earned the highest grades in high school were the ones who slept in until after 7:00 am and obtained more than eight hours of sleep. Interestingly, even though the students who obtained more than eight hours of sleep earned higher grades, they reported much less study time than the students who obtained fewer than eight hours of sleep.

A surprise finding by Cole (2016), was that students who obtained fewer than eight hours of sleep obtained higher SAT and ACT scores compared to the students who obtained more than eight hours of sleep. These students who obtained fewer than eight hours of sleep, but earned higher SAT and ACT scores were also the ones who studied more, causing Cole to come to the conclusion that the decreased sleep obtained by students that is associated with increased studying does not undercut their performance on the ACT or SAT. However, since the ACT and SAT are achievement tests, it comes as a surprise that these students did not earn higher grades in high school. Consequently, Cole stressed the importance and need to research aspects of this paradox further.

While many researchers use grades, grade point averages and test scores as a basis for academic performance when examining sleep duration in the context of schools, Titova et al. (2015) examined the link between sleep duration and the odds of failing academic classes. This study, conducted in Sweden, analyzed sleep duration and academic data provided by 4,736 adolescents who completed the *Life and Health Young Survey*. After controlling for every conceived variable that could potentially impact sleep such as body mass index, location of school, household composition, among other variables, the researchers found that the students who obtained fewer than seven to eight hours of sleep on school nights were at increased odds of failing at least one academic class in the school year. The odds were even greater if the adolescent obtained fewer than seven to eight hours of sleep on school nights *and* weekend nights. While the adolescents were also at risk for failing at least one class if they experienced sleep disruptions such as restlessness and trouble falling asleep, a short sleep duration contributed to a higher risk of academic failure.

In their study conducted in Switzerland, Perkinson-Gloor, Lemola, and Grob (2013) explored the relationship between sleep duration, daytime fatigue, behavioral persistence, well-being, and academic success. Besides looking directly at the relationship between sleep duration and academic performance, the researchers wanted to determine whether behavioral persistence and daytime tiredness serve as mediators between sleep duration and academic performance. Their study was composed of 2,716 adolescents from six different high schools that were mostly made up of immigrant groups and students of a lower socioeconomic status. Their reasoning behind this was the argument that the role poor sleep plays on wellbeing and academic performance is magnified by a lower socioeconomic status. The participants completed online questionnaires which evaluated daytime sleepiness, sleep habits, and behavioral persistence, as well as attitude toward life. German language and math grades for each participant were provided by the school and served as the basis for determining academic performance.

Perkinson-Gloor et al. (2013) found that the participants who reported receiving fewer than eight hours of sleep per night had more daytime sleepiness, had lower behavioral persistence and also received lower German language and math scores compared to the participants sleeping more than eight hours per night. Through their statistical models, they determined that daytime sleepiness and behavioral persistence serve as mediators between sleep duration and academic success. Perkison-Gloor et al. (2013) explained, "The models revealed that short sleep was related to more daytime tiredness, which in turn was related to lower behavioral persistence....Moreover, behavioral persistence was a moderately strong predictor of academic achievement" (p. 315).

Just as Perkison-Gloor et al. (2013) examined a causal pathway linking sleep duration to academic performance, so too did Perez-Lloret et al. (2013). In their study examining 1,194 adolescents in Argentine schools, the researchers sought to connect sleep duration to academic performance through the mediators of daytime sleepiness and attention. They used literature and math grades as the barometers of academic performance. While they did not find a statistically significant direct relationship between sleep duration and academic performance when controlling for gender, age and body mass index, they found correlations between each successive variable in their pathway, ultimately connecting sleep duration to academic performance through the mediators of daytime sleepiness and attention. The researchers' correlational pathway found that short sleep duration was correlated with more daytime sleepiness, which was correlated with reduced attention, which was correlated with lower academic performance. As explained by Perez-Lloret et al. (2013), "short sleep duration would set up a 'chain reaction' with increased daytime somnolence and reduced attention as intermediate links leading to reduced academic efficiency" (p. 472).

Similarly, in their longitudinal study, Sabia, Wang, and Cesur (2017) briefly explored whether homework completion and concentration served as mediators in the relationship between sleep duration and academic performance. They had previously established that increased adolescent sleep duration led to improvements in completing homework and concentration and wanted to see whether these short term improvements were connected to the relationship between sleep duration and academic performance. What Sabia et al. (2017) found was that when they controlled for concentration and homework completion in their statistical analyses, there was a "35%-42% decline in the estimated association between sleep duration and educational attainment" (p. 339-340).

Multiple studies explore the role that sleep duration plays on the academic performance of university students. This is beneficial as the sleep schedules of these older adolescents are not necessarily confined by early school start times due to more flexible class scheduling. Two such studies found that shorter sleep durations in university students were linked to lower grade point averages (Kelly, Kelly, & Clanton, 2001; Raley, Naber, Cross, & Perlow, 2016). Kelly et al. (2001), whose study included undergraduate students with the average age of 19.86 years, classified short sleepers as those receiving a nightly duration of six or fewer hours of sleep and long sleepers as those receiving a nightly duration of nine or more hours of sleep. They found that sleep duration had a statistically significant effect on grade point average, with the long sleepers having higher grade point averages compared to the short sleepers. Likewise, Raley et al. (2016), whose study included university students with the average age of 21.38 years, found that the students receiving the most sleep in the study had higher grade point averages while the students receiving the least amount of sleep had lower grade point averages.

Two research studies examining university students which specifically used exam scores as the basis for academic performance determined the importance of obtaining sufficient sleep in the consecutive nights preceding an exam rather than just obtaining sufficient sleep the night before an exam (Scullin, 2019; Okano, Kaczmarzyk, Dave, Gabrieli, & Grossman, 2019). In the Scullin (2019) study, students in a psychology class examining sleep were incentivized with extra credit at the end of the semester if they obtained an average of eight hours of sleep per night in the week leading up to their final exam. The students who chose to participate in this challenge were required to wear actigraphy devices at night. All students in the class were required to wear actigraphy devices at the beginning of the semester in order to form a baseline for their sleep durations. Scullin found that with the incentive of extra credit, students increased their sleep duration, averaging 8.17 hours of sleep per night, and there was less variability in their sleep durations from night to night. Their sleep schedules were more consistent when compared to the baseline data.

The interesting revelation, however, generated by the Scullin (2019) study is regarding the final exam performance of the students who completed the challenge compared to those who did not. The students who averaged eight hours of sleep per night in the week leading up to the final exam scored significantly better on their final exam compared to the students who did not participate in the challenge and had less sleep. As explained by Scullin (2019), "Succeeding on the 8-hr sleep challenge was associated with the equivalent of a 4.9 (corrected) to 7.6 (uncorrected) point boost on the final exam" (p. 61). This finding debunks the myth that students must sacrifice sleep for study time during final exams week and students can still perform well on exams while obtaining sufficient sleep. As explained by Scullin (2019), one student in the study who was earning a D previously in the class but who completed the eight-hour challenge indicated it was the "first time my brain worked while taking an exam" (p. 61).

Similar to the study by Scullin (2019) , Massachusetts Institute of Technology students in a chemistry class wore Fitbit sleep tracking devices for an entire semester for a study conducted by Okano, Kaczmarzyk, Dave, Gabrieli and Grossman (2019). The researchers created an aggregate test score for each student comprising the scores of eight quizzes and three midterm exams taken by the students throughout the semester to form the basis for academic performance. The researchers found that the average sleep duration of the students throughout the semester was significantly and positively associated with their aggregate score. Interestingly, the researchers found that the sleep duration obtained by the students on the night before an exam or quiz was not significantly associated with their respective test scores. However, the sleep duration obtained for the month before a midterm exam or for the week before a quiz was significantly associated with the students' respective scores on the midterms or quizzes. Because of this revelation, Okano et al. (2019) pointed out the importance of obtaining sufficient sleep during the time frame in which the content in the exams and quizzes is taught rather than only getting sufficient sleep the night before an exam or quiz.

Research from further studies strengthen the association between sleep duration and academic performance. In the pre-post study conducted by Dunster et al. (2018), the researchers observed that student grades increased by 4.5% after their average sleep duration increased by 34 minutes from the school start time change in Seattle. In their study of middle school students, Lewin et al. (2017) found that the students who obtained eight hours of sleep per night had the largest probability of earning A's compared to the students who obtained fewer than seven hours of sleep per night, and sleep duration was significantly and positively associated with grades. In Hong Kong, while Ng, Ng, and Chan (2009) did not find an association between sleep duration and the students' English grades, they did find a significant positive association between sleep duration and the students' mathematics grades. Lastly, Wahlstrom et al. (2014) reported a small but statistically significant association between student school night sleep duration and self-reported grades.

Counterarguments. Just as there is research debunking the strength of the relationship between school start times and sleep durations, there is also a body of research examining the relationship between sleep duration and academic performance that exposes caveats and conflicting evidence. For instance, one interesting observation Perkison-Gloor et al. (2013) drew from their research, is that eight hours of sleep appeared to be the threshold driving their statistical relationships. The National Sleep Foundation (2006) as cited in Perkison-Gloor et al. (2013) considers nine hours or more of sleep a night to be an optimal amount of sleep for adolescents and anywhere between eight to nine hours of sleep to be an acceptable amount of sleep. However, the researchers observed there was no clear advantage to receiving optimal sleep versus acceptable sleep on the variables of behavioral persistence and academic achievement. Thus, for example, there were no major differences between the behavioral persistence and academic achievement of students who received eight hours of sleep compared to those who received eleven hours of sleep, but there were major differences in these variables once students received fewer than eight hours of sleep.

Just as Perkinson-Gloor et al. (2013) determined there is no apparent academic benefit to receiving more than nine hours of sleep a night, Sabia et al. (2017) found that there are diminishing returns and academic costs to receiving longer sleep. Sabia and his colleagues analyzed the data from the *National Longitudinal Study of Adolescent to Adult Health* (Add Health) which surveyed thousands of adolescents in 1994 to 1995 and surveyed the same group again in follow up interviews conducted in 1996, 2001, and 2008. Overall, Sabia et al. (2017) found that sleep duration is positively correlated with the academic performance measures of grade point average, homework completion, and paying attention in class, but to a certain extent. They determined that receiving eight hours of sleep leads to maximized benefits for grade point average and receiving around nine hours of sleep leads to maximized benefits for homework completion and paying attention, leading the researchers to determine that the optimal amount of sleep to maximize academic benefits is 8.5 hours of sleep. Receiving more than 8.5 hours of sleep leads to diminishing returns and a decline in academic benefits. This is an interesting revelation considering the sleep recommendation for 14 to 17 year olds is eight to 10 hours of sleep per night as explained in Hirshkowitz et al. (2015).

Likewise, using educational attainment data obtained through the follow up interviews of the Add Health study, Sabia et al. (2017) determined the optimal amount of sleep per night associated with the probability of graduating high school and attending college. They determined that the probability of graduating high school is maximized at averaging 8.6 hours of sleep per night and the probability of attending college is maximized at averaging 7.4 hours of sleep per night. In spite of their findings, which indicate longer sleep can be detrimental to academic performance, Sabia and his colleagues argued that since the majority of the participants in their study obtained fewer than 8.5 hours of sleep per night, an increase in sleep duration brought on by later school start times would academically benefit many students who obtain fewer than 8.5 hours of sleep per night.

Like Sabia et al. (2017), Asarnow, McGlinchey, and Harvey (2014) also used results from the Add Health study to assess the impact of total sleep time on long term educational performance. They used data from the initial Add Health interview conducted in 1994 to 1995 and from two of the follow-up interviews conducted in 1996 and 2001 to 2002 (which they labeled Wave I, Wave II, and Wave III respectively). While Asarnow et al. (2014) determined that a late bedtime during the school year in Wave I and Wave II was associated with a lower grade point average six to eight years later in Wave III, the researchers found no such association between total sleep time and grade point average. This finding negated their hypothesis that short total sleep time in Wave I and Wave II is predictive of a lower grade point average in Wave III and came as a surprise to the researchers.

In their study which included 1,000 high school students and 200 middle school students, Eliasson, Eliasson, King, Gould, and Eliasson (2002) found no association between sleep duration and student grade point average. Instead, they determined that time spent doing homework was the largest predictor of grade point average. As a result, Eliasson and his colleagues argued that “the cost of later school start times would be more wisely invested in after-school tutor/mentor programs, homework clubs, or teacher improvement efforts (Eliasson et al. 2002, p. 47-48).

Further studies expose evidence that challenges the notion that there is a positive relationship between sleep duration and academic performance. Like the findings of Sabia et al. (2017), Taylor, Vatthauer, Bramoweth, Ruggero, and Roane (2013) found that there is a curvilinear relationship between sleep duration and grade point average in undergraduate college students. They found that in addition to a short sleep duration, a long sleep duration was also predictive of a lower grade point average compared to an intermediate sleep duration. Ming et al. (2011) found that averaging fewer than seven hours of sleep on school nights was not significantly associated with average grades, and such an association existed only if sleep duration was fewer than seven hours on both school nights *and* weekend nights. Lastly, Eide and Showalter (2012) determined that the optimal amount of sleep for 16 year olds to maximize their performance on subtests of the Woodcock-Johnson standardized test is between 7.02 and 7.35 hours per night, and the optimal amount of sleep for 18 year olds to maximize their performance on the same tests is under seven hours per night. This is well below the amount of sleep that is recommended adolescents receive.

Impact on Attendance and Tardy Rates

One mechanism by which earlier school start times may negatively impact academic performance is by students missing early morning instruction time because of decreased attendance or increased tardiness. Many of the studies examining the impact of school start times on academic performance and sleep duration also briefly examine the impact of school start times on attendance and tardy rates. Given these studies, the evidence appears scattered regarding the extent to which school start times impact attendance and tardy rates, with the impact on tardy rates being more pronounced than the impact on attendance rates. For instance, in their meta-analyses, Bowers and Moyer (2017) found that in the three studies examining school start times and tardiness, later school start times were associated with decreased tardiness. However, with the three studies examining school start times and attendance, Bowers and Moyer found no significant association between school start times and absences.

Two previously cited longitudinal studies on school start times and sleep durations found varying results regarding attendance and tardy rates (Thacher & Onyper, 2016; Dunster et al., 2018). In their study of the upstate New York school which delayed its school start time by 45 minutes, Thacher and Onyper (2016) found that the unexcused and excused absence rate actually increased after the shift to a later school start time. While the attendance rate did not improve, Thacher and Onyper found that even though the rate of excused tardiness stayed the same before and after the school start time change, the rate of unexcused tardiness decreased significantly, by 20%, which decreased the overall tardy rate.

When examining the two Seattle high schools which delayed their school start times by 55 minutes, Dunster et al. (2018) found varying results on attendance and tardy rates between the two schools. They observed that in one school, there was no change in the attendance or tardy rates after the school start time change, but in the other school, absence and tardy rates declined significantly. An observation pointed out by the researchers regarding this discrepancy in data is that the school that showed the significant decline in tardiness and absences was the one whose students were much more ethnically diverse and who had a lower socioeconomic status.

In one of the first longitudinal studies examining the impact of a later school start time, the Center of Applied Research and Educational Improvement (CAREI), whose findings are reported in Wahlstrom (2002), examined attendance rates over a five year period before and after the Minneapolis Public School District delayed its high school start times from 7:15 am to 8:40 am. The researchers found that from the two years before the start time change to the three years after the start time change, the attendance rate for continuously enrolled students did not change. Wahlstrom (2002) defined continuously enrolled students as those attending the same high school for at least two consecutive years. However, the attendance rate for discontinuously enrolled students, who often moved from school to school in the district, increased at a rate that was statistically significant. Also, when compared to demographically similar students in another school district whose school start time was 7:30 am, Wahlstrom (2002) found that the students attending the Minneapolis Public School District were less likely to report being tardy to class as a result of oversleeping.

Despite the previous evidence indicating that attendance rates are not predominantly affected by later school start times, one study found significant decreases in absences due to illness after a school in England delayed its start time by one hour and ten minutes (Kelley, Lockley, Kelley, & Evans, 2017). In this study, school start times changed from 8:50 am to 10:00 am, which are times that are much later than what has typically been studied. The England school in this study was a low achieving school performing well below the national average. Kelley et al. (2017) found that before the school start time change, students in the experimental school averaged 15.4 absences due to illness, which was 34% higher than the national average that year of 11.5 absences. While having a 10:00 am start time for two consecutive school years, the number of average absences per student decreased to 11.3 the first year and then to 7.9 the second year, which was 10% lower than the national average. During year three, in which the experimental school went back to an 8:50 am start time, the number of average absences reeled back to 11.2, which was above the national average again.

Two previously cited studies and one study not previously cited report further findings on how attendance and tardy rates are affected by later school start times. When Wolfson et al. (2007) compared two demographically similar middle schools with school start times that were 82 minutes apart, they found no statistically significant differences in the attendance rates between the two schools, but they found that the students attending the early starting school had four times as many instances of tardiness as the students attending the later starting school. When examining the impact of school start time delays in five school districts across three states, Wahlstrom et al. (2014) observed statistically significant increases in school attendance rates in two districts, but overall the majority of the changes in attendance rates were insignificant and the results across the schools were inconsistent. However, Wahlstrom and her colleagues observed that most schools had a significant decrease in tardiness after the delay in school start times. When examining data across all middle schools in Wake County, North Carolina for two different school years, Edwards (2012) determined that students who had a school start time one hour later compared to earlier starting schools, had 1.3 fewer absences per year.

Impact on Academic Performance

Heretofore, with some caveats and counterarguments, the evidence has established that later school start times generally increase sleep durations, longer sleep durations can improve academic performance, and later school start times generally impact tardy rates more than attendance rates. Also, previously cited evidence on the synchrony effect established that people generally perform better on certain tasks during times of day that align with their chronotype, and adolescents are more susceptible to having an evening chronotype. All this evidence aside, there are multiple studies that seek to establish a direct link between school start times and academic performance, with these studies using grades and standardized test scores to form the basis for academic performance. However, after extensive research, there appears to be less literature examining the direct link between school start times and academic performance compared to the literature examining the link between school start times and sleep duration.

Without examining sleep duration, Carrell et al. (2011) examined the impact of school start times on the academic performance of freshman at the United States Air Force Academy (USAFA). During the four-year span of the data collection used by the researchers, USAFA changed their first period start time from 7:30 am to 7:00 am, and then from 7:00 am to 7:50 am. Also, many students started their school day even later than the aforementioned times because students at USAFA are randomly assigned whether they start their day during the first period or during the second period. Using math and science grades as the basis for academic performance, Carrell et al. (2011) found that students who did not have a first period class earned higher grades overall than students who had a first period class. Interestingly, the students who were assigned a first period class earned lower grades overall in all subsequent classes for that day, not just in the early morning classes, when compared to students who did not have a first period class. Likewise, of the students who did have a first period class, higher overall grades were associated with the later start time (7:50 am as opposed to 7:00 am). The researchers determined that delaying the start time by 50 minutes, from 7:00 am to 7:50 am, "has the equivalent benefit as raising teacher quality by roughly one standard deviation" (Carrell, Maghakian, & West, 2011, p. 80).

Carrell et al. (2011) provided two explanations as to why students who were assigned a first period class were at an academic disadvantage. First, these students were in class during a time that did not align with their circadian timing; they were in class when their bodies wanted to be asleep. Secondly, they may have obtained less sleep than the students who were not assigned a first period class. As explained by Carrell et al. (2011), "The positive effect of later start times we find is reflective of the synchronization of learning to optimal times of day and possibly also increased amounts of sleep," (p. 79).

Even though the USAFA is a post-secondary institution, Carrell and his colleagues justified why their study is applicable to the high school population and why their findings are relevant. First, their participants were freshmen students who had the same biological mechanisms at play as younger adolescents. Likewise, during the time of the study, freshmen attendance to all classes at USAFA was mandatory, class sizes were small, and the school day was highly structured and followed a schedule like one found in a typical high school. Also, to reduce grading bias and to standardize grades, all staff members teaching the same subject at USAFA used the same syllabi, administered the same exams, and collaborated with one another to assign semester grades. Despite these study strengths, Sabia et al. (2017) argued it is ambiguous whether the findings by Carrell and his colleagues would be the same for the general population compared to a military population. Even though the adolescents in the Carrell et al. (2011) study were high achievers compared to typical teenagers, Carrell and his colleagues argued because their study participants were used to a disciplined lifestyle, the impact of their study findings may be even more robust on the general population of teenagers.

Unlike Carrell et al. (2011) which used math and science grades as a basis for academic performance, Edwards (2012) used math and reading standardized test scores to determine the potential impact school start times play on academic performance. During the years 1999 to 2006, Edwards collected school start time data and standardized test score data from all middle schools in Wake County, North Carolina. During this time, school start times were variable across different schools and school start times also changed within schools from year to year. To reduce bias and present more accurate findings, Edwards focused primarily on pre and post data within schools that experienced a school start time change.

While controlling for specific school and student characteristics, Edwards (2012) determined that a one hour delay in school start times is associated with a 1.5 percentile increase in standardized reading scores and a two percentile increase in standardized math scores. To put his findings into context, Edwards (2012) explained that:

> For math scores, the effect of a 1 h later start time is roughly 14% of the black-white test score gap, 40% of the gap between those eligible and those not eligible for free or reduced price lunch and 85% of the gain associated with an additional year of parental education (p. 977).

Edwards observed that the impact of a one hour school start time delay on test scores is more pronounced for the students whose scores typically fall in the lower end of the score distribution, supporting his argument that later school start times may help schools that need to meet minimum competency standards put in place by the government. Despite his findings, Edwards cautioned that the gains found from his study should not be considered universal since the impact may be more or less significant with schools starting later than the ones in his study. For instance, the gains that occur when schools start at 8:15 am may be more or less than the gains that occur when schools start at 9:15 am.

The study by Kelley et al. (2017) examined the impact on academic performance of a much later school start time than what is typically studied. This study, which was previously cited in the attendance and tardy rates section of this literature review, involved the underachieving English school that changed its start time from 8:50 am to 10:00 am for two school years and then back to 8:50 am in the third school year. The researchers used the percentage of students who successfully completed the General Certificate of Secondary Education (GCSE), a standardized examination completed at the conclusion of compulsory education, as the basis for academic performance. Before the start time change, the number of students to successfully complete the GCSE was well below the national norm, 34% compared to 56.2%. One year after the start time change, 53% of the students successfully completed the GCSE which was still below the national norm but the difference from the national norm was now statistically insignificant. During the second year of the start time change, 52% of the students completed the GCSE, making the difference from the national norm statistically insignificant again. When the school switched back to an 8:50 am start time, Kelley and his colleagues found that while 51% of the students successfully completed the GCSE, there was a decrease in success relative to the national norm, which was now at 60%, and the difference from the national norm became statistically significant again, just as it was before the school delayed its start time initially.

In the Kelley et al. (2017) study, the researchers provided further insights regarding having a much later start time than what is typically recommended. First, given their findings, they explained that "the general policy recommendation to start high schools no earlier than 8:30 am, while helpful, should not be taken as justification to exclude consideration of much later starting times" (Kelley et al., 2017, p. 7). Since the original starting time of 8:50 am in the study was already later than typical recommendations, Kelley and his colleagues argued that starting schools even later could lead to more improvements. The researchers also pointed out that very expensive educational policies in England and the United States such as ones created to close the achievement gap between different students, the creation of charter or STEM schools, and No Child Left Behind, have had minimal impact relative to the cost-effective gains achieved by the 10:00 am start time in their study.

Further studies have examined a direct link between school start times and academic performance, although their evidence is not as compelling as the evidence revealed until now. When studying the impact of university class scheduling (class frequency and start time) on academic performance, Dills and Hernandez-Julian (2008) found a very small but significant effect between student grades and class start time, with students earning the highest grades in the afternoon. They determined that each one-hour delay in class start time throughout the day is associated with a .024 grade point increase. When controlling for sleep duration and demographics in their middle school study, Lewin et al. (2017) found a direct relationship between school start times and grades, but only with the earliest school start times of 7:20 am to 7:30 am. For school start times after 7:30 am, school start times only indirectly impacted grades through the mediator of sleep duration. Lastly, while Wahlstrom et al. (2014) observed statistically significant grade point average increases across all grade levels in five high schools after the school start time delays in her pre-post study, no clear statistically significant patterns developed regarding pre-post changes in standardized test scores.

Counterarguments. For nearly every study found with evidence of a direct link between school start times and academic performance, there appears to be a study providing evidence against such a direct link. For instance, Wahlstrom (2002), who was previously cited for reporting the benefits of delayed school start times on attendance and tardy rates, found no apparent benefit of a later school start time on grades. When examining letter grades for the three years before the Minneapolis Public School District delayed its high school start times by one hour and 25 minutes and for the three years after the delay, Wahlstrom determined that while grades improved minimally, there were no statistically significant changes.

Wahlstrom (2002), however, argued against using grades to measure the impact of a school policy change. Issues such as grading subjectivity, grade inflation, teacher turnover, and grading variability between different teachers and school districts cause grades to be an unstable form of measurement to determine policy change effectiveness. Wahlstrom (2002) pointed out that “a conclusion from the time-consuming and intensive data analysis examining actual grades earned is that districts will find it difficult to use letter grades when judging the efficacy of school start time changes” (p. 11). Despite these issues pointed out by Wahlstrom, the findings on grades from the Carrell et al. (2011) study at the United States Air Force Academy should still be considered valid given the academy’s use of practices to diminish grading issues such as the use of universal examinations, universal syllabi, and teacher collaboration to assign grades.

Hinrichs (2011) studied the same start time policy change enacted by the Minneapolis Public School District that Wahlstrom (2002) studied, but instead of using grades to measure the effectiveness of the policy change, Hinrichs used individual student ACT scores. Hinrichs collected data on ACT exams taken between 1993 and 2002 from the Minneapolis Public School District, as well as from many other schools in the Twin Cities area in order to have a control group. In addition, Hinrichs conducted analyses on standardized test score data collected between 2000 and 2006 from every high school in Kansas and from 75 high schools in Virginia, to determine the potential impact of school start time changes enacted in those states during that time. After conducting robustness checks and controlling for many different variables, Hinrichs revealed that his analyses found no school start time effect on ACT scores in Minnesota or on standardized test scores in Kansas and Virginia. Interestingly, when using a quadratic model for his Kansas data, however, Hinrichs observed that delays in start times until 8:07 am were associated with increased test scores but start time delays after 8:07 am were associated with decreased test scores. This finding is analogous to previously cited evidence of potential plateau effects and diminishing returns found by researchers studying sleep duration and academic performance.

In the previously cited study by Thacher and Onyper (2016) in which an upstate New York school delayed its high school start time by 45 minutes, the researchers used grade point averages and standardized test scores to determine the potential impact of the start time change on academic performance. When examining grade point averages longitudinally for the same students before and after the start time change, Thacher and Onyper found no evidence indicating the start time change had any impact on grade point averages. Likewise, when examining grade point averages cross sectionally, comparing the ninth, 10th, 11th, and 12th grades before the start time change to the same grades after the start time change, the researchers found no statistically significant differences between the different grade point averages. The researchers found the same to be true when examining standardized test scores cross-sectionally. There appeared to be no evidence that the school start time change had any impact on standardized test scores when comparing tests taken before and after the start time change.

Two previously cited studies found further evidence questioning the potential direct link between school start times and academic performance. When examining a 25-minute delay in the start time at a boarding school, Boergers et al. (2014) found that the change did not appear to affect self-reported grades of the students. In the comprehensive study by Rhie and Chae (2018) which included tens of thousands of students in South Korea, grade point averages increased each year of the study in both the experimental group schools and the control group schools. Therefore, any impacts the school start time delays had on the grade point averages of students at the experimental group schools could not be confirmed.

CHAPTER III: DISCUSSION AND CONCLUSION

Summary

Regarding sleep, adolescence is a tumultuous time for individuals. With the onset of puberty, adolescents are biologically predisposed to stay up later at night and wake up later in the morning compared to their preadolescent counterparts or adults. Likewise, they experience many environmental changes that affect their sleep habits such as less parental involvement regarding bedtime rules, increased caffeine use, working part time jobs, and increased electronic use before bed. Despite these factors that affect adolescent sleep, adolescents around the world must wake up well before they are biologically ready to do so in order to attend school. While in school, they may be required to perform academic tasks during times that do not align with their chronotype, going against the synchrony effect.

A possible solution often posed to help adolescents obtain the sleep they need is to delay school start times. This literature review sought to examine the relationships between school start times and sleep duration, sleep duration and academic performance, school start times and attendance and tardy rates, and school start times and academic performance in order to better determine if a delay in school start times is the end all solution to solve the adolescent sleep crisis. When examining the relationship between school start times and sleep duration and between sleep duration and academic performance, there is an overwhelming amount of evidence supporting the links between the variables in these relationships and some evidence negating the strength of the relationships. The evidence was less abundant when examining the relationship between school start times and attendance and tardy rates and when examining a direct link between school start times and academic performance.

Regarding the relationship between school start times and sleep duration, most of the evidence indicates that there is a positive association between school start times and sleep duration. The studies revealed that with later school start times, the probability of adolescents obtaining sufficient sleep is much greater and adolescents sleep longer by means of waking up later in the morning. Studies that used self-reported data and actigraphy data found this to be true. Two studies (Rhie & Chae, 2018; Thacher and Onyper, 2016) did find that the increased sleep durations associated with school start time delays did not last indefinitely as adolescents experiencing school start time delays eventually adjusted their bedtimes to later times. Even though the evidence overwhelmingly reveals that later school start times lead to more sleep, the findings of Rhie and Chae and Thacher and Onyper should not be dismissed and should be examined further.

An overwhelming amount of evidence found that sleep duration is associated with academic performance. The previously cited studies in this thesis reveal that there is a modest effect size of sleep duration on academic performance and longer sleep durations are generally associated with higher self-reported grades and grade point averages. Shorter sleep durations are associated with increased odds of failing classes and lower grade point averages. It was also determined that obtaining sufficient sleep in the week and months leading up to quizzes and exams is more important for exam performance than just obtaining sufficient sleep the night before a quiz or exam. Multiple studies determined that sleep duration impacts academic performance by means of influencing mediators between the two variables such as behavioral persistence, daytime sleepiness, concentration, attention, and homework completion.

The impact that school start times have on attendance and tardy rates does not appear as clear cut as the impact it has on sleep duration and the evidence reveals that school start times appear to impact tardy rates more than attendance rates. All the studies examining both attendance rates and tardy rates found that later school start times were associated with decreased tardy rates, but not every study found a benefit of delayed school start times on attendance rates. One study did find that a later school start time was associated with a significant decrease in absences due to illness (Kelley et al. 2017), but no other clear cut patterns in regard to attendance rates were found with other studies.

Overall, there appears to be less published research examining direct associations between school start times and academic performance. Even then, for nearly every study finding a direct link between school start times and academic performance, there is a study where no association is found by the researchers. This thesis cited six studies in which a direct positive association was found between school start times and various measures of academic performance such as grade point averages, grades, and performance on standardized tests. Five studies which examined the direct link between school start times and academic performance could not confirm any significant associations between school start times and grade point averages, grades, or performance on standardized tests. These discrepancies justify the need for further precise studies of true experimental or longitudinal design to get a more accurate picture of the effects of school start times on academic performance. These discrepancies also suggest the possibility that sleep duration by means of mediating factors or by means of a direct link plays a larger role on impacting academic performance than school start times do.

One apparent trend found through the data on the impact of school start times on attendance rates, tardy rates, and academic performance is that later school start times appear to benefit students who are disadvantaged in some way the most, such as students of a lower socioeconomic status. For instance, in the study by Dunster et al. (2018), the high school that saw a significant decline in tardiness and absences after a school start time delay was the school that was very ethnically diverse and whose students had a lower socioeconomic status. In the Wahlstrom (2002) study, a school start time delay benefited the attendance rates of only those students who frequently moved from school to school. The school in the Kelley et al. (2017) study was very underachieving compared to the rest of England but saw a significant decrease in absences due to illness and a significant increase in students successfully completing exit exams after a school start time delay. Lastly, the students in the Edwards (2012) study whose standardized test scores typically fall in the low end of the test score distribution were the ones whose scores benefited the most from a school start time delay. These revelations suggest that later school start times can be one step in the right direction towards closing the achievement gap and leveling the playing field for all subgroups in the student population.

The data on the impact of school start times on sleep duration and the impact of sleep duration on academic performance reveals other trends that cannot be ignored. It is observed that there is often a plateau effect or diminishing returns when examining the impact of school start times on sleep duration and the impact of sleep duration on academic performance, and different demographics are impacted differently by different school start times. Paksarian et al. (2015) determined that the positive impact school start times have on sleep duration plateaus with start times around 8:01 am, and the size of the impact differs amongst different demographic groups. For instance, the strongest positive association between school start times and sleep duration was found for urban males, no association was found for females, and a negative association was found for rural males. Two studies revealed that academic benefits from sleep maxes out at eight hours and 8.5 hours of sleep respectively, and there is no apparent academic benefit to obtaining more sleep (Perkison-Gloor et al., 2013; Sabia et al., 2017). Further studies revealed different sleep amounts that maximize academic performance and showed that a longer sleep duration is not always best to maximize academic benefits. These trends show that certain school start times may not be appropriate for all school districts and demographics, and school districts need to enact school start times that maximize the benefits for all their students.

Professional Application

The most important first step I can take with the information presented in this literature review is to educate—educate students and parents about the sleep changes that occur during adolescence that can negatively impact adolescent daily school functioning. As pointed out previously by Nahmod et al. (2019), many students who start school at 8:30 am or later still obtain insufficient sleep based on recommendations laid out by the National Sleep Foundation. According to Dunietz et al. (2017), nearly 50% of parents surveyed considered fewer than seven hours of sleep for their adolescents as a “sufficient or possibly sufficient” amount of sleep, and roughly 90% of parents surveyed considered seven to seven and a half hours of sleep for their adolescents as a "sufficient or possibly sufficient" amount of sleep (p. 893). These statistics illustrate the misconceptions families may have regarding adolescent sleep needs.

I believe implementing adolescent sleep hygiene education for families would be an important first step when considering a school start time delay policy change. Unless families understand the sleep changes that occur during adolescence and the sleep needs of adolescents, they may not understand the reasoning behind why school districts may seek to implement school start time delay policy changes. Information from this literature review can help inform families about these major sleep changes that occur during adolescence so that they may be more open to the idea of a school start time change. Within the classroom setting, I can provide lessons on sleep hygiene to my students using the information from this thesis and I can reach out to parents who are open to it and provide them with the same information. With everything I have learned about adolescent sleep by conducting this literature review, I too can become more understanding of and patient with my students who may exhibit sleepiness in their early morning classes.

Limitations of Research

As with all research studies, there are limitations to the studies presented in this thesis. First, given the nature of the variables of school start times, sleep duration, attendance and tardy rates, and academic performance that were in the studies, it was difficult for many studies to follow a true experimental design. Many studies retroactively conducted analyses on data that was collected from school start time policy changes that occurred previously. School start times cannot be manipulated in a laboratory setting, leading to natural experiments surrounded by many underlying factors that are out of the control of the researchers. For instance, in many studies, the researchers examining the data surrounding school start time policy changes couldn't control for the magnitude of the start time change, the demographics of the students involved, the wake times of the students, or grading biases, among other things.

Many of the studies were cross-sectional, comparing different populations of students who may or may not have gone through a school start time change, rather than longitudinal. Given the nature of the variables involved, one would think a longitudinal study, examining the impacts of a school start time change on the same population over time, would provide a more accurate representation of the potential impacts. Even then, as showed through the study by Paksarian et al. (2015), the impacts of a school start time change may differ based on regionality, student demographics, or population density of the school location. Therefore, researchers and school districts must understand that the findings of a longitudinal study conducted in one part of the world, may be quite different if the same study were conducted in another part of the world.

Other limitations need to be addressed. While many studies made use of actigraphy sleep data and academic performance data provided by school districts, many other studies relied on self-reported sleep and academic performance data, which may not be as accurate. In the studies examining academic performance, no universal measure of academic performance was used across studies, making it difficult to judge the true impact of sleep durations and school start times on academic performance. Some studies used self-reported grades, some used the probability of passing or failing classes, some used grade point averages, and some used standardized test performance as measures of academic performance. Similarly, the student populations being studied differed from study to study, making it difficult to generalize the findings across studies. For instance, the student populations examined in this thesis ranged from university students attending USAFA, to high school boarding school students, to students in an underachieving public high school. Lastly, many studies only reported on the short-term impacts of later school start time changes and did not determine if those impacts were long lasting, over the course of multiple school years.

Implications of Future Research

The complexity of the findings from this literature review raises many questions and identifies points that need to be clarified through future research studies. Many studies found a very weak connection or no connection between the variables being studied, and much can be learned from those studies that were summarized under the counterarguments sections of this literature review. Further research should examine exactly why discrepancies between the different research studies exist and why some studies found larger relationships between the variables being studied compared to other studies. Were such discrepancies due to the specific statistical analyses the researchers decided to use? Were they due to the demographics of the study population or population size? Determining why discrepancies exist can help make future studies examining sleep durations and school start times more accurate.

This literature review revealed the possibility that different demographics of students are affected by school start time changes differently and there may be an optimal school start time and sleep duration that maximizes academic benefits. Further studies should look to provide clarification on these topics. The relationship between demographics and school start times should be further studied to determine what demographic group, if any, may benefit the most from a school start time delay. Likewise, future studies should seek to provide clarity on whether there is a universal optimal school start time and optimal sleep duration that can maximize academic benefits, and future studies should provide clarity on the universality and reliability of the plateau effects and diminishing returns that were so often observed in the studies summarized in this literature review. One thing I would personally like researched in future studies is whether the efficacy of a school start time delay can be more robust when implemented jointly with mandatory district wide sleep hygiene education in secondary schools. Further research into these topics may help answer some questions regarding closing various achievement gaps that are so often seen in school districts.

It is often pointed out that changing school start times is not an end all solution. With regards to helping students obtain more sleep, the Adolescent Sleep Working Group, Committee on Adolescence, and Council on School Health (2014) points out:

> It should also be emphasized that delaying school start times alone is less likely to have a significant effect without concomitant attention to other contributing and potentially remediable factors, such as excessive demands on students' time because of homework, extracurricular activities, after-school employment, social networking, and electronic media use (p. 646).

Likewise, Sabia et al. (2017) explains that "the academic benefits and costs of later school starting times are just one set of parameters necessary for a full social welfare analysis" (p. 340). Given these caveats, future studies need to examine further the extent to which other factors besides school start times weigh on adolescent sleep and how school start times can work in tandem with these other factors.

Conclusion

The studies explored in this thesis sought to determine the extent of the impact that school start times have on sleep duration, sleep duration has on academic performance, school start times have on attendance and tardy rates, and school start times have on academic performance. With some caveats, the findings from the studies reveal that generally, later school start times lead to longer sleep durations and longer sleep durations are associated with better academic performance. Also, there is evidence that later school start times improve tardy rates, can improve attendance rates, and is positively associated with academic performance.

What works for one school district in terms of school start times may not work for all school districts as the complexity of the findings in this paper suggest one size does not fit all, and school districts need to consider the school start time that benefits all of its secondary students the most. The findings in this literature review reveal, if anything, that there are no disadvantages in terms of sleep duration, attendance and tardy rates, and academic performance to delaying school start times. The best outcome for a school district to delay its school start time would be for students to obtain more sleep, have improved attendance, be more punctual, and experience academic performance gains. The worst possible outcome would be for students to experience no changes to these variables after a school start time delay, but a school start time delay would not disadvantage them in any way. Given the potential benefits later school start times have for students, I believe it would be a disservice for school districts with earlier school start times not to at least consider enacting a later start time that is so often recommended by the various professional organizations specializing in sleep and adolescent health.

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