

EXPLORING THE LONGITUDINAL EFFECTS OF SLEEP AND PHYSICAL ACTIVITY
ON ACADEMIC ACHIEVEMENT ACROSS MIDDLE CHILDHOOD AND ADOLESCENCE

BY

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THESIS

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ABSTRACT

Objective: Research has documented normative declines in school motivation and achievement across adolescence. There is some evidence to suggest that engaging in sufficient levels of sleep and physical activity across the transition to middle school might support subsequent achievement. Less is known about the role of pubertal development and sex in the relationship between health behaviors (e.g., sleep and physical activity) in middle childhood and changes in achievement across middle childhood and adolescence. **Method:** Participants in the NICHD Study of Early Child Care and Youth Development were followed from birth through age 15, starting in 1991. Sleep and physical activity were assessed when children were in 6th grade achievement was assessed in 5th grade and again at age 15. Structural equation modeling was used to test associations between sleep, physical activity and directly assessed achievement and child reported academic self-concept across middle childhood and adolescence. **Results:** Findings suggest that there are long-term effects of sleep, indexed by self-reported general sleep problems, on changes in picture vocabulary skills. Children who report more sleep problems in 6th grade experienced greater declines in picture vocabulary skills across middle childhood and adolescence. Hours of sleep, time spent in physical activity, and time spent in sedentary behavior were not significantly associated with achievement outcomes. **Conclusion:** Sleep problems in middle childhood appear to have adverse effects on verbal comprehension skills across middle childhood and adolescence. These findings provide some evidence that improving sleep quality in middle childhood may help minimize losses in verbal comprehension and crystallized intelligence across middle childhood and adolescence.

Keywords: Achievement, adolescence, physical activity, sleep.

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CHAPTER 1: INTRODUCTION

Early adolescence is marked by significant changes in cognitive, social, and biological development (Adams & Berzonsky, 2003; Keating, 2004; Lerner & Steinberg, 2009; Smetana, Campione-Barr, & Daddis, 2004). Although the majority of youth navigate these changes with moderate ease, they can be challenging for others. Research has documented normative declines in indicators of school motivation and performance during early adolescence (Alspaugh, 1998; Eccles & Midgley, 1989; McGill, Hughes, Alicca & Way, 2012; Wang & Eccles, 2012a; Wang & Pomerantz, 2009). In particular, youth commonly experience declines in competence beliefs, mastery orientation, interest in school, a sense of belonging in school, school participation, self-regulated learning, and overall engagement in school (Wang et al., 2012a; Wigfield, Eccles, Schiefele, Roeser & Davis-Kean, 2006). This is of particular importance, given that research indicates achievement in adolescence is a significant predictor of future orientation and outlook on long-term career potential (Negru-Subtirica & Pop, 2016). Indeed, academic success in childhood and adolescence predicts future wealth, health, and productivity (Mikkonen & Raphael, 2010; Woolf, 2007). The transition to middle school is particularly challenging, where students engage in a larger, bureaucratically structured system allowing for greater student autonomy as they encounter more teachers, peers, and class choices (Eccles & Harold, 1996; Hill & Chao, 2009). Augmenting these changes are higher teacher expectations, more difficult work, and greater academic pressures (Midgley, Anderman & Hicks, 1995). Thus, these years are particularly challenging for youth. Given these structural and biological changes, coupled with the decline in academic achievement, understanding and identifying individual-level day-to-day

experiences that might support early adolescent learning is essential. Two such experiences are sleep and physical activity.

Sleep and Achievement

Efforts to understand the underlying mechanisms impacting academic achievement have increasingly focused on the role of sleep, since sleep is believed to play a critical role in achievement, learning and brain plasticity (Curcio, Ferrara, & De Gennaro, 2006; Dewald, Meijer, Oort, Kerkhof & Bögels, 2010; Fredriksen, Rhodes, Reddy, & Way, 2004; Walker, 2009; Wolfson & Carskadon, 2003). Sleep can be defined as a multidimensional construct, characterized by changes in brain wave activity, breathing, heart rate, and other physiological functions (National Sleep Foundation, 2006). Sleep is thought to revitalize and restore the physiological processes that keep the body and mind healthy and functioning properly (Horne, 1988; Oswald, 1980). Indeed, more and better quality sleep has been associated with better health, enhanced memory, better emotion regulation, improved concentration, better quality of life and better overall psychological functioning (Baum, Desai, Field, Miller, Rausch & Beebe, 2014; Chaput, Gray, Poitras, Carson, Gruber, Olds, ... & Belanger, 2016; Moore, Kirchner, Drotar, Johnson, Rosen, Ancoli-Israel, & Redline, 2009; Sadeh, 2007). Getting sufficient sleep each night has also been associated with positive behavioral outcomes like better school grades, fewer hours of watching television and playing video games, and more days eating breakfast and lunch (Lange, Cohrs, Skarupke, Görke, Szagun & Schlack, 2017; Stroebele, McNally, Plog, Siegfried & Hill, 2013).

Conversely, extant literature has shown that inadequate sleep can disrupt processes that occur in the prefrontal cortex like executive functioning, an essential tool for emotion regulation and cognitive control (Jones & Harrison, 2001). Indeed, less sleep is associated with lower

cognitive functioning, working memory, and overall academic performance (Bub, Buckhalt, & El-Sheikh, 2011; Curcio et al., 2006; Fredriksen et al., 2004; Perkinson-Gloor, Lemola, & Grob, 2013; Thomas, Monahan, Lukowski, & Cauffman, 2015; Wolfson et al., 2003). This could be because poor sleep undermines neural development and daily emotion regulation functions, important tools for academic achievement (Baum et al., 2014; Dewald, et. al., 2010; Owens, Dearth-Wesley, Lewin, Gioia, & Whitaker, 2016). Indeed, sleep deprivation also predicts more emotional and behavioral difficulties and increased psychological stress (Brand, Kirov, Kalak, Gerber, Schmidt, Lemola, & Hosboer-Trachsler, 2016; Fuligni & Hardway, 2006; Sadeh, Tikotzky, & Kahn, 2014; Smaldone, Honig, & Byrne, 2007; Wolfson et al., 2003; Yip, 2015). Inadequate sleep has also been found to predict poorer self-esteem and higher rates of depression among adolescence, both of which are associated with lower overall achievement (Fredriksen et al., 2004). Sleep problems might also prevent the process of information learned in school being moved into long-term memory (Born & Wilhelm, 2012; Kopasz, Loessl, Hornyak, Riemann, Nissen, Piosczyk, & Voderholzer 2010). Indeed, deficits in working memory have been associated with increased likelihood of risky behaviors like drug and alcohol use, safety violations and increased violence (Thomas et al., 2015). Thus, daily inadequate sleep has significant implications for academic behaviors, academic achievement, and cognitive development.

Adolescence appears to be a time of particular vulnerability to sleep problems (Logan, Hasler, Forbes, Franzen, Torregrossa, Huang, & McClung, 2017; Thomas et al., 2015). Natural shifts in the circadian rhythm, coupled with increased academic, social, and extracurricular pressures, have led to considerable declines in sleep duration and sleep quality during this period (Bartel, Gradisar, & Williamson, 2015; Colrain & Baker., 2011; Crowley, Van Reen,

LeBourgeois, Acebo, Tarokh, Seifer, & Carskadon, 2014; Logan et. al., 2017). According to National Sleep Foundation, 45% of youth between the ages of 11 and 18 are not getting the recommended 8-11 hours of sleep on school nights (Adolescent Sleep Working Group, 2014; Colrain et al., 2011; Curcio et al., 2006; Fredriksen et al., 2004; Hirshkowitz, Whiton, Albert, Alessi, Bruni, DonCarlos, & Neubauer, 2015; National Sleep Foundation, 2006; Thomas et al., 2015). On school nights, it is estimated that 26% of adolescents get less than 6.5 hours of sleep, which could lead to diminished functioning across multiple domains (Barnes, Davis, Mancini, Ruffin, Simpson, & Casazza, 2016). Furthermore, up to 28% of adolescents also report falling asleep in school, and 1 in 5 report falling asleep doing homework at least once per week (National Sleep Foundation, 2006).

Although increasing evidence supports the link between sleep and achievement, gaps in our knowledge still remain. We know very little about the role that sleep plays in learning and achievement across the transition to middle school. It may be that youth who experience sleep problems across this transition are particularly vulnerable to the increased academic and social pressures they experience in middle school. Since the majority of existing sleep studies are cross-sectional rather than longitudinal, they cannot adequately address this question and thus there is a need for additional longitudinal research. Thus, one goal of the current study is to better understand the longitudinal associations between sleep duration or sleep problems and academic achievement from middle school to high school.

Physical Activity and Achievement

Physical activity may also explain declines in school engagement and performance across the adolescent transition. Research has shown that physically active children and youth outperformed their less active peers academically (Arday, Fernandez-Rodriguez, Jiminez-Pavon,

Castillo, Ruiz, & Ortega, 2014; Esteban-Cornejo, Terejo-Gonzalez, Sallis, & Veiga, 2015; Fedewa & Ahn, 2011; London & Castrechini 2011). In fact, research suggests that academic gaps between physically active youth and their non-active peers may begin as early as fourth grade, and continue to expand as student's advance (London et al., 2011). A 2-year study revealed that adolescence at a healthy fitness level in both the pre and post-test had significantly higher scores on achievement tests than did their peers who did not have a healthy fitness level at either test. Interestingly, these less fit peers also did worse than students who tested as fit once in either the pre or post-test (Wittberg, Northrup, & Cottrell, 2012). These effects might be due to the influence of physical activity on cognition, which subsequently impacts achievement (Arday et. al., 2014; Esteban-Cornejo et. al., 2015; Hillman, 2014). Indeed, physical activity has been positively linked to executive functioning, attention, inhibition, self-regulation, and memory, important cognitive skills for academic achievement (Soga, Shishido, & Nagatomi, 2015; Strong, Malina, Blimkie, Daniels, Dishman, & Gutin, 2005; Van der Niet, Smith, Scherder, Oosterlaan, Hartman, & Visscher, 2015; Ziereis & Jansen, 2015). Greater engagement in physical activity is also associated with better behavioral and emotional outcomes; like lower levels of participation in risk behaviors, lower rates of suicide, more positive health outcomes, and higher self-esteem (Brown, & Blanton, 2002; Nelson, & Gordon-Larsen, 2006; Patel, & Luckstead, 2000; Southerland, Zheng, Dula, Yan, & Slawson, 2016). Adolescents who engage in organized sports also tend to hold more positive beliefs about their ability to succeed in multiple areas of life (Gisladdottir, Matthiasdottir, & Kristiansdottir, 2013).

Despite this evidence linking physical activity with better outcomes, research suggests that middle and high school students are engaged in sedentary behavior for 6-8 hours of their day (Matthews, Chen, Freedson, Buchowski, Beech, Pate, & Troiano, 2008). Though physical

activity is typically stable from 5-8 years of age, it falls progressively from ages 9-15 (Metcalf, Hosking, Jeffery, Henley, & Wilkin, 2015). Indeed, a study of 4,867 participants revealed that overall physical fitness declined dramatically from childhood to adolescence, with 42% of children ages 6-11 years old engaged in the recommended 60 minutes of physical activity per day, but only 8% of adolescents (Troiano, Berrigan, Dodd, Masse, Tilert, & McDowell, 2008). This progressive decline in physical activity is paralleled by a consistent decline in achievement across secondary school (McGill et al., 2012). Indeed, sedentary behavior is negatively associated with academics (Kantomaa, Stamatakis, Kankaanpaa, Kajantie, Taanila, & Tammelin, 2016; Nigg, & Amato, 2015; Syvaaja, Kankaanpaa, Kallio, Hakonen, Kulmala, Hillman, & Tammelin, 2017; Tremblay, LeBlanc, Kho, Sanders, Larouche, & Colley, 2011). Kantomaa et al. (2016) found that youth who engaged in high levels of sedentary behavior were significantly less likely than their more active peers to have a high grade-point average. Furthermore, more time spent in sedentary behavior is associated with lower self-esteem, unfavorable behavior conduct, greater engagement in risky behaviors and lower pro-social behavior (Carson, Hunter, Kuzik, Gray, Poitras, Chaput, ... & Kho, 2016; Nelson et al., 2006). Compounding this problem is the removal of physical education classes from public education. Many school districts are reducing physical education requirements, with some programs cut entirely (Thomas, 2004). The percentage of schools requiring physical education decreases from approximately 50% in elementary school, to 25% in 8th grade, to 5% in 12th grade (Burgeson, Wechsler, Brener, & Young, 2001). Coupled with these declines in activity are increased rates of teacher-reported attention problems and a growing concentration deficit (Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008; Van der Niet et al., 2015).

Although considerable research has examined the links between physical activity and learning, findings have been inconsistent. Some studies have suggested that more physical activity is associated with better academic outcomes in early childhood (Becker, McClelland, Loprinzi, & Trost, 2014; Käll, Nilsson, & Lindén, 2014), middle childhood (Gao, 2013; Hansen, Herrmann, Lambourne, Lee, & Donnelly 2014; London et al., 2011; Mullender -Wijnsma, Hartman, Greeff, Bosker, Doolaard, & Visscher, 2015), and adolescence (Bunketorp Käll, Malmgren, Olsson, Lindén, & Nilsson, 2015; Coe, Peterson, Blair, Schutten, & Peddie 2013; London et al., 2011; Trudeau, & Shephard, 2008). Other studies have found negative associations between physical activity and English scores (Daley, & Ryan, 2000). Still others have found no association (Ahamed, Macdonald, Reed, Naylor, Liu-Ambrose, & McKay, 2007; Coe, Pivarnik, Womack, Reeves, & Malina, 2006; Corder, Atkin, Bamber, Brage, Dunn, Ekelund, & ... Goodyer, 2015). Additionally, some studies have found that physical activity is related to cognition, not academic performance (Donnelly, Hillman, Greene, Hansen, Gibson, Sullivan, ... & Herrmann, 2017). Thus, the direction and magnitude of the relationship between physical activity and academic achievement remains unclear. Importantly, the majority of work in this area has been cross-sectional rather than longitudinal, so we know little about the potential benefits of physical activity across middle childhood and adolescence. This may be a particularly important period to study, given the declines in achievement and physical activity across adolescence. An additional goal of the current study is to understand the direct effects of physical activity in middle childhood on achievement across middle childhood and adolescence.

Sleep and Achievement with Physical Activity

Research has indicated that youth who engage in more physical activity also tend to experience more and better quality sleep (Bartel et. al., 2015; Dworak, Wiater, Alfer, Stephan,

Hollmann, & Struder, 2008; Foti, Eaton, Lowry, & McKnight-Ely, 2011; Lang, Kalak Brand; Holsboer-Trachsler, Puhse, & Gerber, 2016; Mendelson, Borowik, Michallat, Perrin, Monneret, Faure, & Flore, 2016). A study of 14,782 adolescents revealed that students who partook in the recommended 60 minutes of physical activity per day were more likely to obtain the recommended hours of sleep per night, when compared with their less active peers (Foti et. al., 2011). Indeed, individuals who exercise more frequently demonstrate better slow wave sleep, less light sleep, higher scores for positive coping, and scored lower for depressive symptoms (Brand, Gerber, Beck, Hatzinger, Puhse, & Holsboer-Trachsler, 2010). Furthermore, physical activity has been associated psychological factors related to sleep (Brand, Gerber, Clough, Lemola, Sadeghi Bahmani, ... & Holsboer-Trachsler, 2017; O'Connor, Raglin, & Martinsen, 2000). Bartel et. al. (2015) observed that good sleep hygiene and physical activity were associated with earlier bedtimes. There is also evidence that sufficient sleep predicts greater engagement in physical activity (Stroebele et al., 2013). Moderate levels of physical activity and sleep have been linked to a myriad of positive outcomes, including a healthier lifestyle, better cognitive performance during development, better self-regulation and greater academic success (Hillman, 2014; Matricciani, Olds, & Petkov, 2012; Pindus, Davis, Hillman, Bandelow, Hogervorst, Biddle, & Sherar, 2015). Specifically, Fanning et. al. (2017) found that replacing sedentary behavior with sleep or moderate-to-vigorous physical activity can bolster several important domains of self-regulatory behavior and executive functioning, important mechanisms that support academic achievement. Conversely, Syvaioja, et. al. (2017) found that a later bedtime mediated the negative effects of time spent in sedentary behavior (screen-time) on grade-point average.

Although a breadth of research indicates a relationship between sleep, physical activity, and achievement, some research indicates that the relationship between sleep and physical activity is not bidirectional at all, instead suggesting that physical activity predicts sleep, but sleep does not significantly predict physical activity (Ekstedt, Nyberg, Ingre, Ekblom, & Marcus, 2013). Other studies have found no significant association between daily physical activity and sleep (Youngstedt, Perlis, O'Brien, Palmer, Smith, Orff, & Kripke, 2003). Additionally, although some research has examined the effects of sleep and physical activity on health outcomes (Lee, Williams, Brown, & Laurson, 2015), academic outcomes are rarely considered. Finally, much of the research on physical activity has used a cross-sectional or year-long design, limiting our knowledge of the long-term links between physical activity, sleep and achievement, particularly in middle childhood and adolescence. Given these mixed findings, the direction and magnitude of the relationship between sleep and physical activity remains unclear and further work is needed to clarify this relationship. Another goal of the current study is to examine the association between sleep and physical activity in middle childhood, and subsequent academic achievement in adolescence.

The Transition to Middle School

Research suggests that the transition to middle school lays the foundation for future academic, social-emotional, and behavioral development (Akos, Lineberry, & Queen, 2015). Yet, this transitional period has been historically characterized by losses in achievement (Akos et al., 2015; Alspaugh, 1998; Coelho, Marchante, & Jimerson 2017), sleep (Fredriksen et al., 2004), and physical activity (Johnson, Erwin, Kipp, & Beighle, 2017; Parish & Treasure, 2003). Indeed, students report significant decreases in academic, emotional, and physical self-concept across the transition to middle school (Coelho et al., 2017). Goldstein, Boxer & Rudolf, (2015)

discovered that stress related to the middle school transition predicted lower grades, lower school bonding and higher school anxiety. Middle school students also report more daytime sleepiness than their elementary school counterparts (Surani, Hesselbacher, Surani, Sadasiva, Surani, Surani,..., & Subramanian, 2015). This concerning, since youth who sleep less at the beginning of 6th grade exhibit more depressive symptoms, lower self-esteem and lower grades in subsequent years (Fredriksen et. al., 2004). Youth who experience less sleep across the transition to middle school also engage in less healthy eating habits than their more rested peers (Franckle, Falbe, Gortmaker, Ganter, Taveras, Land, & Davison, 2015). Similarly, as youth enter middle school, engagement in physical activity declines significantly while time spent in sedentary behavior increases (Barr-Anderson, Flynn, Dowda, Schenkelberg, Reid, Pate, & Ross, 2018; Lau, Dowda, Mciver, & Pate, 2017; Parish et al., 2003; Pearson, Haycraft, Johnston, & Atkin, 2017). A study by Barr-Anderson et al. (2018) revealed that time spent in physical activity declines significantly from 5th to 7th grade across racial/ethnic and socio-economic groups. This is of particular importance, since research suggests that engagement in sufficient levels of moderate-to-vigorous physical activity across the transition to middle school helps maintain healthy levels of body mass index (BMI) and weight (Dowda, Taverno Ross, McIver, Dishman, & Pate, 2017). Interestingly, middle school boys tend to be more active and have a greater enjoyment of PE than middle school girls (Johnson et. al., 2017; Parish et al., 2003).

While emerging literature links the transition to middle school to declines in achievement, physical activity and sleep (Coelho et al., 2017; Fredriksen et al., 2004; Johnson et al., 2017), inconsistencies and gaps remain. Although a breadth of research indicates that sleep development parallels achievement development, some research has found that the slope of sleep across middle school is unrelated to the slope of grades (Fredriksen et. al., 2004). While some

research indicates gender differences across the transition to middle school (Johnson et. al., 2017; Parish et al., 2003), other research observes no gender differences (Coelho et al., 2017). A study by Nelemans, Hale, Branje, Meeus, & Rudolph (2017) suggests the transition to middle school can alter the developmental trajectory of anxiety for some youth, but in both positive and negative ways. Thus, it is important to clarify the longitudinal effects of this transitional period in future work. Another goal of the current study is to examine sleep and physical activity following the transition to middle school, and their subsequent effects on academic achievement.

Biological Differences in Sleep, Physical Activity and Achievement

Research has indicated that sex might be related to sleep, physical activity and academic achievement. Girls tend to get more sleep (Fredriksen et al., 2004; Moore, Kirchner, Drotar, Johnson, Rosen, & Redline, 2011; Olds, Blunden, Petkov, & Forchino, 2010) and demonstrate greater ‘morningness’ orientation than boys (Randler, 2011). This could be explained by the research indicating males have a later chronotype than females in adolescence (Adan, Archer, Hidalgo, Di Milia, Natale, & Randler 2012). Indeed, boys experience less overall sleep, lower sleep efficiency, later bedtime on weekends, and later wake time throughout the week than girls (Gaina, Sekine, Hamanishi, Chen, & Kagamimori, 2005). However, Fredriksen et. al. (2004) found that, while girls obtained more sleep than boys at the start of middle school, and both sexes saw a drop in sleep quantity over time, this decline was at a significantly steeper rate for girls. Indeed, negative associations between sleep problems and achievement are stronger in girls than in boys (Bub et. al., 2011; Meijer, 2008). For example, Bub et. al. (2011) discovered that, when boys and girls both reported high levels of sleepiness, boys verbal comprehension continued to improve whilst girls did not. Despite girls reporting less boredom in school and higher achievement motivation, boys report better academic self-concept (Meijer, Van Den, &

Meijer, 2000). This may be due to the fact that girls tend to be more fearful of negative evaluations in school than boys (Hartmann, Zahner, Puhse, Schneider, Puder, & Kriemler, 2010). Incidentally, higher levels of self-esteem in boys is associated with higher reading scores (Srikanth, Petrie, Greenleaf, & Martin 2015). In a study of 1,361 youth, Brand et. al. (2017) found that girls scored significantly lower on indices of subjective sleep, psychological functioning, mental toughness, and physical fitness than their male counterparts. Indeed, boys tend to engage in more physical activity than girls (Pizarro, Schipperijn, Ribeiro, Figueiredo, Mota, & Santos 2017; Viciania, Mayorga-Vega, D., & Martínez-Baena, 2016). Trost, Pate, Sallis, Freedson, Taylor, Dowda, & Sirard (2002) found that boys tend to engage in much more vigorous activity than girls, but in only slightly more moderate-to-vigorous activity. This could be why girls displayed more positive math outcomes and less hyperactivity than their male counterparts in a physical activity intervention study (Kall, 2015).

Similar to sex, developmental shifts due to the onset of puberty have been associated with sleep, physical activity and achievement across adolescence. Recently, greater attention has been given to the role of pubertal development in sleep patterns. Preference for evening hours appears during puberty (Randler, 2011). Indeed, pubertal development marks a transition for youth from a 'morningness' orientation to an 'eveningness' one (Carskadon, Vieira, & Acebo, 1993; Carskadon, Acebo, & Jenni, 2004; Diaz-Morales & Sorroche, 2008; Laberge, Petit, Simard, Vitaro, Tremblay, & Monrplaisir, 2001; Randler & Frech, 2006). At the time of pubertal onset, youth begin to experience later sleep and more night waking, manifesting as a shift of up to 2 hours sleep time delay from middle childhood (Frey, Balu, Greusing, Rothen, & Cajochen, 2009). This might be due to the correlations between pubertal stage and circadian phase markers, with more mature children showing a later phase of melatonin secretion offset.

In fact, developing youth report less overall sleep on school nights (Taylor, Jenni, Acebo, & Carskadon, 2005). Adolescents at later pubertal stages also report a greater midday sleep tendency than their peers (Carskadon et al., 2004). Martin & Steinbeck (2017) found that pubertal status negatively predicted participants' academic motivation, and lower academic motivation was predictive of lower academic achievement. Thus, participants further into puberty reported lower motivation, and subsequently lower achievement.

Sex differences in pubertal development might also impact sleep and physical activity, as well as subsequent academic achievement. Puberty has been linked to steeper age-related declines in physical activity, but only in girls (Metcalf et al., 2015). Early physical maturation in girls has been associated with increased risky behaviors (Arim, Tramonte, Shapka, Dahinten, & Willms, 2011), higher levels of school problems (Aro & Taipal, 1987; Grabel et al., 1997), and lower grades (Cavanaugh, 2007; Martin et al., 2017). Additionally, while early pubertal development is linked to more externalizing problems in both sexes, it is also linked more internalizing problems in girls (Beltz, Corley, Bricker, Wadsworth, & Berenbaum, 2014). Conversely, early and average maturation in boys is associated with more positive academic outcomes (Koivusilta & Rimpelä, 2004).

Despite these findings, the impacts of sex and puberty remain inconsistent. While some research suggests significant sex differences in academic achievement, other studies have found no sex differences (Becker et al., 2014; Montroy, Bowles, Skibbe, & Foster, 2014; Zan, 2013). Some research studies have also indicated that girls report worse sleep quality than boys (Brand, et al., 2017; Hysing, Pallesen, Stormark, Lundervold, & Sivertsen, 2013; Meijer, Reitz, Deković, Van den Wittenboer, & Stoel, 2010; Wolfson & Carskadon, 1998) and report more daytime sleepiness than boys (Gaina, Sekine, Hamanishi, Chen, Wang, Yamagami, & Kagamimori,

2007). Still other studies found no association between sex and school sleep variables (Martinez-Gomez, 2012; Laberge et al., 2001). Similarly, some studies suggest that pubertal development is not associated with sleep (Pesonen, Martikainen, Heinonen, Wehkalampi, Lahti, Kajantie, & Rääkkönen, 2014; Laberge et al., 2001), physical activity (Niven, Fawkner, Knowles, & Stephenson, 2007), or academic outcomes (Dubas, Graber, & Petersen, 1991). Thus, further work is needed to understand the interactions between these factors. Additionally, most research studies are cross-sectional or conducted over the course of a single year, limiting our understanding of this complex relationship. Thus, the roles of sex and puberty in the relationship between sleep, physical activity and achievement is relatively unknown. Another goal of the current study is to examine the role that sex and puberty might play in this relationship.

Current Study

Increasing evidence indicates a link between sleep, physical activity and academic achievement across middle childhood and adolescence, where increases in sleep and physical activity are positively associated with achievement (Ardoy et al., 2014; Bub et al., 2011; Lange et al., 2017; Wittberg et al., 2012). However, much of the research examining physical activity and academic achievement has been short-term or cross-sectional studies, limiting our understanding of the long-term impacts of physical activity on achievement. Additional evidence supporting this link could provide much-needed insight into novel avenues for improving academic achievement across the transition to puberty. Although sleep and physical activity have been associated with achievement, inconsistencies in the research have left critical gaps in our understanding of these associations. For example, few studies have examined the effects of sleep on achievement longitudinally across the pubertal transition, and fewer studies have examined the moderating roles of physical activity, sex, and puberty. Thus, we know little

about the long-term effects of sleep on achievement and whether these effects vary for different youth. A clearer understanding of this relationship may provide significant insights into novel methods for improving academic achievement across middle childhood and adolescence. We begin to address these gaps by addressing the following research questions: 1) Do youth reports of sleep quality and quantity in 6th grade predict changes in academic achievement and self-concept across middle childhood and adolescence? 2) Do physical activity and sedentary behavior in 6th grade predict changes in academic achievement and self-concept across middle childhood and adolescence? 3) Do the associations between sleep in 6th grade and changes in academic achievement and self-concept differ by time spent in physical activity? 4) Do these associations differ by child sex or pubertal status? We expect that better quality and more sleep in 6th grade will predict smaller declines in achievement from middle childhood to adolescence. We also expect that time spent in moderate-to-vigorous activity, sex, and pubertal status will moderate the strength of this association, such that youth who experience better sleep and more time engaged in physical activity will experience smaller declines in achievement, when compared with their less active peers.

CHAPTER 2: METHODS

Participants

In the present study, researchers used data from phases III and IV of the *National Institute of Child Health and Human Development (NICHD) Study of Early Child Care and Youth Development (SECCYD)*. Phase III included 2nd through sixth grade, and phase IV included 7th grade to age 15. In 1991, families were recruited to participate at hospitals shortly after birth in 10 different collection sites. These sites included Little Rock, AR; Irvine, CA; Lawrence, KS; Boston, MA; Philadelphia, PA; Pittsburgh, PA; Charlottesville, VA; Morganton, NC; Seattle, WA; and Madison, WI. Recruitment began in January 1991 and was completed in November 1991. In the sampling period, 8,986 new mothers were visited in the hospital to determine their qualification for the study, and 5,151 met eligibility requirements. Major exclusion criteria included mother's health, being younger than 18 at child's birth, not an English speaker, planning to move in the next 3 years, and babies with obvious disabilities at birth or remained in the hospital for more than 7 days postpartum. A conditional random sampling plan was used to select 2,352 families and 1,364 participated. The method incorporated the following clauses: (1) 60% were mothers who planned to work or go to school full-time in child's first year of life, (2) 20% were mothers planning to work or attend school part-time during child's first year, and finally (3) 20% were mothers who planned to stay at home full-time with the child. The recruited families included 24% ethnic minority children, 11% mothers without a high school education, and 14% single mothers. Beginning at the time of enrollment (a home visit when the study child was one month old), families were scheduled for periodic data collection. The sample is not considered nationally representative. White, non-Hispanic children are overrepresented in the sample, while ethnic minority children are relatively underrepresented. In

study families, average household income level and maternal education attainment are higher than the US average (NICHD Early Child Care Research Network, 2001).

Attrition and Missing Data

Phase I (1991-1994) tracked the study children from birth to 3 years. Assessments were completed when the study child was 1, 6, 15, 24, and 36 months old. In phase II (1995-2000), 1,226 children (89.9%) continued to participate from 3 years to 2nd grade. Assessments were completed at 54 months, kindergarten, and first grade. Phase III (2000-2005) followed the remaining 1,061 children (77.8%) from 2nd to 6th grade. Assessments were completed at 2nd, 3rd, 4th, 5th, and 6th grades. In phase IV (2005-2008), 1,009 children (74.0%) remained in the study. Phase IV assessments were completed at 7th and 8th grades and at age 15.

Procedure

Data for the current study were gathered when participating children were in 5th grade, 6th grade, and at age 15 via direct assessment, youth self-report, and parent report. Specifically, direct assessments and youth self-reports of academic achievement were collected when the study child was in 5th and 6th grade, and at age 15. Youth self-reported sleep was collected when the study child was in 6th grade. Direct assessments of time spent in physical activity were collected when the study child was in 6th grade. Youth reported sedentary behavior was collected when the study child was in 6th grade. Maternal reports of pubertal status were collected when the study child was in 6th grade. Direct assessments of Body Mass Index (BMI) were collected when the study child was in 6th grade. Maternal reports of income were collected when the study child was in 5th and 6th grade, and at age 15. Finally, demographic information such as sex, mother's education, and child ethnicity were collected via maternal report during home visits when the study children were one month old. Further information on sample

selection and study procedures can be found elsewhere (see NICHD ECCRN, 2001 or visit the study website at <http://www.nichd.nih.gov/research/supported/seccyd.cfm>).

Measures

Outcome Variables

Direct Assessment of Academic Skills. At 5th grade and age 15, subjects were administered *The Woodcock-Johnson Psycho-educational Battery Revised* (WJ-R; McGrew, Werder, & Woodcock, 1991; Woodcock, 1990). The WJ-R is a comprehensive set of individually administered tests measuring a range of cognitive abilities and a set of achievement skills. Scores on two subscales were used for the current study: Picture Vocabulary and Applied Problems. The *Picture Vocabulary* subscale assesses cognitive ability by asking subjects to identify familiar and unfamiliar pictured objects. The *Applied Problems* subscale assesses the study child's ability to solve practical problems in mathematics through question analysis, identification of the proper procedure, and calculation the solution. The Test of Cognitive Ability maintains high internal consistency, with Picture Vocabulary at .70-.82 and validity of $r = .69$ when it was compared with the *Peabody Picture Vocabulary* test. Tests of Achievement's test-retest reliability for the individual tests range .80-.87. Validity was also strong with a .60s correlation between the *Skills Cluster* and *Boehm Test of Basic Concepts* as well as the *Bracken Basic Concepts Scale*, and the tests have been found to be valid measures of adolescents' cognitive functioning (McGrew, 1993; McGrew, 1994; McGrew & Hessler, 1995; McGrew, & Knopik, 1993; Woodcock & Johnson, 1989).

Self-Concept of Academic skills. At 6th grade and age 15, study children were administered *How I Do in School* to assess self-concept in academic subjects and sports. Children completed the 19-item questionnaire to assess their expectations for their educational

attainment through attending high school, college, and finishing college. The measure also assessed their perceived achievement in the domains of English, math, and sports. Each subject had 5 items assessing student's perception their abilities in that particular subjects. Specific questions included "How do you expect to do in SUBJECT this year?" And "How good at SUBJECT are you?" Scores on the English self-concept and Math self-concept subscales were used for the current study. Scores were rated on a 7-point scale, with higher self-concept associated with higher scores. The scores were then averaged to create a composite self-concept score. The raw items used to create scores have moderate internal reliability for both math self-concept (5 items, Cronbach's $\alpha = .84$) and English self-concept (5 items, Cronbach's $\alpha = 0.83$).

Predictor/Moderator Variables

Youth Reports of Sleep. Study children completed the *My Sleep Habits* questionnaire in an interview format during their 6th grade year. This 19-item questionnaire used a 5-point Likert scale (*1 = never, 3 = sometimes, 5 = always*) to examine children's bedtimes, amount of sleep, and difficulties going to sleep on the previous night, and weekends and weekdays in general. Additional questions assessed night waking's (one item), difficulty getting up on time on school day mornings (one item), feeling tired on school days (one item), and the child's wish to get more sleep (one item). Youth reported general sleep problems was used for the current study. Responses to all items were summed and scores ranged from 8 to 40, with higher scores indicating more sleep problems. Items were adapted from the *Children's Sleep Habits Questionnaire* (Owens, Spirito & McGuinn, 2000). The Composite demonstrated moderate internal consistency ($\alpha = 0.77$).

Physical Activity Monitor. *Physical Activity Monitors* (PAM) were worn by subjects at 6th grade in order to assess their physical activity levels. PAM devices are single channel

accelerometers that record accelerations, measuring a person's total movement over a defined period of time. Subjects wore the devices on their non-dominant hand for seven days during a typical school week. Frequency of activity was calculated and categorized into Moderate, Vigorous, or Very Vigorous activity. Moderate-to-Vigorous activity was constructed from the summed minutes of Moderate, Vigorous, and Very Vigorous Activity. Scores for Moderate-to-Vigorous activity were used for the current study. Thirty children (7-15 years old) wore the devices for 12 hours per day over 6 days to test the reliability of these devices. Through ICC and 95% confidence interval analysis, the accelerometer was stable using 1 monitored day ($r = .42-.47$), and increased in stability after 6 days of use ($r = .81-.84$). Four days of use ($r = .75-.78$, CI = $.60-.88$) was deemed as the minimum amount of days for the monitor to be worn in order to obtain adequate reliability. Further tests of 381 children demonstrated that 4 days of monitor use was necessary to reliably measure Moderate, Vigorous, and Very Vigorous activity, but seven days was necessary for acceptable reliability in Moderate-to-Vigorous Activity.

Youth Reported Activity. The *Self-Administered Physical Activity Checklist* (SAPAC) is a self-report, interviewer-administrated, one-day recall of physical activity and sedentary behavior when the study child was in 6th grade. This checklist consists of 24 physical activities with space for listing up to two 'other' activities, and one additional section to report TV/video/DVD viewing and video/computer game playing. Children were asked if they spent any time (defined as 5 minutes or more) during the previous school day participating in each activity. If their answer is yes, they were asked the number of minutes they believe they spent participating in that activity at 3 time points (before school, during school, after school). The number of activities, and minutes per sedentary, light, moderate, and heavy activity were computed as well as time watching TV, videos, and playing computer games. The SAPAC

classifications were validated using heart rate data, showing good reliabilities (Sallies et al., 1996).

Pubertal Development. Maternal reported pubertal status of study child was obtained using the *Pubertal Development Scale*, a measure developed by Anne Peterson (Peterson, Crocket, Richards, & Boxer, 1988). Mothers were asked to assess pubertal status by evaluating the degree to which specific physical change (e.g. pimply skin, growth spurt, etc.) had occurred. Separate measures were used for boys and girls. Ratings on a 5-point scale were 1 = No, 2 = Yes, barely, 3 = Yes, definitely, 4 = Development completed, and 5 = Don't know. Responses of "don't know" were recoded as missing and the five items were averaged to create a summary score reflecting pubertal development, with higher scores indicating more advanced pubertal development. Forms were completed beginning at age 9 ½ and then each year until the child reached Tanner stage 5 on both assessments. Reliability coefficients were moderate for boys ($\alpha = .62$) and girls ($\alpha = .76$). The *Pubertal Development Scale* has been widely used to describe pubertal stage by adolescents, parents, and observers (Brooks-Gunn, Warren, Rosso, & Gargiulo, 1987; Petersen et al., 1988). In addition to the continuous scale, we created a dichotomous indicator of pubertal status for the analyses. Youth whose score was a 3 or 4 were given a score of 1, reflecting advanced pubertal status; all other youth were given a score of 0 to reflect little or no pubertal development if their pubertal development score was 1 or 2.

Sex. Maternal reports of child sex were collected when the study child was one month old. Males were given a score of 1 and females were given a score of 0.

Control Variables.

Attention Deficit Hyperactivity Disorder. Maternal reports of Attention Deficit Hyperactivity Disorder (ADHD) were obtained using the *Disruptive Behavior Disorders Rating*

Scale when the study child was in 5th grade, based on the original *Disruptive Behaviors Disorders* (DBD) rating scale (Pelham, Gnagny, Greenslade, & Milich, 1992). This 26-item questionnaire was designed to assess mothers' and teachers' perceptions about the behavior of the study child. The form is adapted from the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders. Items were scored on a 4-point rating scale where 0 = not at all, 1 = just a little, 2 = pretty much, 3 = very much. ADHD was computed from the sum of 18 items, with higher scores indicating more attention deficit-hyperactivity behaviors. The ADHD items demonstrated high reliability ($\alpha = 0.92$).

Body Mass Index. Direct assessments of *Body Mass Index (BMI)* were taken when the study child was in 6th grade. Nurse practitioners measured height and weight during the *Health and Physical Development Exam*. Order of measuring height and weight was not important. For weight, children were asked to remove easily removable sweaters or jackets that could significantly increase their weight score. BMI was calculated through a program provided by the *Centers for Disease Control*, where weight (in kilograms) was divided by height (in meters) squared. The program also provide gender and age adjusted Z-scores and percentiles for BMI, Weight-for-Age, and Height-for-Age. The program is located at:
<http://www.cdc.gov/nccdphp/dnpa/bmi/bmi-for-age.htm>.

Income-to-needs. Family income levels were obtained via maternal report when the study child was in 5th and 6th grade, and at age 15. An *income-to-needs ratio* was computed by dividing a family's total income by the federal poverty threshold for a family of that size, as determined by the *US Bureau of the Census* (US Bureau of the Census, 2004).

Race/Ethnicity. Information on race/ethnicity was collected via maternal reports when the study child was one month old. A single dummy variable indicating whether the child was European American (1=European American, 0=all other races and ethnicities) was created.

Maternal Education. Mother's education level was obtained when the study child was one month old, and reflects the total number of years of formal education the mother had completed. Education was scored where 1 = less than high school, 2 = high school graduate, 3 = some college, 4 = college graduate, and 5 = graduate education.

Data Analysis Plan

Since reliability for each measure was initially established using the full NICHD SECCYD sample of 1,364 children, we examined reliability estimates for each composite variable in the subsample of participants used for the current study. Expected composite scores were reliable in this sample. Means, standard deviations, and intercorrelations among the primary study variables were examined in preliminary analyses using SPSS version 19. All predictive analyses were conducted using Stata Version 10.

To investigate whether sleep in 6th grade was associated with changes in achievement across middle childhood and adolescence, we fit a series of longitudinal structural equation models, regressing directly assessed achievement (picture vocabulary and applied problems) or youth reported self-concept (English self-concept and math self-concept) on self-reported general sleep problems and hours of sleep in 6th grade. To investigate whether physical activity (assessed when children were in 6th grade) was associated with changes in achievement (assessed when children were in 6th grade and at age 15), we regressed directly assessed achievement (picture vocabulary and applied problems) or youth achievement self-concept (English self-

concept and math self-concept) on directly assessed physical activity and youth reported sedentary behavior in 6th grade.

Finally, to investigate the moderating role of physical activity in the relationship between sleep and changes in academic achievement, we added to our models an interaction between youth reported sleep (or hours of sleep) and either physical activity or sedentary behavior. This interaction was regressed on our directly assessed or youth reported achievement outcomes. As such, we were testing whether the link between sleep and changes in achievement (or self-concept) differed by physical activity (or sedentary behavior). In all cases, separate models were fitted for directly assessed achievement outcomes and youth reported self-concept achievement outcomes. These tests of moderation were repeated to examine the moderating roles of sex and pubertal status in the relationship between sleep and achievement outcomes. Additionally, a three-way interaction between physical activity, puberty, and child sex on directly assessed academic achievement and self-concept across middle childhood and adolescence was also tested.

Child (e.g., sex, ethnicity), family (e.g., maternal education, income-to-needs) and previous test score (e.g., picture vocabulary and applied problems in 5th grade, self-concept in 6th grade) were included as controls on the outcome variables (e.g., Self-concept in 6th grade, picture vocabulary at age 15, applied problems at age 15). Similarly, child (e.g., sex, ethnicity), family (income-to-needs) and health (BMI, pubertal status, ADHD symptoms) control variables were included on the predictor variables (e.g., sleep in 6th grade, physical activity in 6th grade). As such, the regression parameters can be interpreted as the association between sleep, physical activity and achievement, controlling for a range of child, family and health factors. Since individuals are likely to be missing data on one or more measures, we will use full information

maximum likelihood (FIML) in Stata Version 10 to estimate the values of our parameters in the cases including missing data.

CHAPTER 3: RESULTS

Preliminary Analyses

Means and standard deviations for all outcome, predictor and moderator variables are presented in Table 1. As expected, directly assessed picture vocabulary and applied problems declined over time. Self-concept in English and math declined with age, but the standard deviation for both increased, suggesting that as youth age, there is greater variability in their perceptions of their own academic skills. Youth reported moderate levels of sleep problems in sixth grade (see table 1), indicating that sleep problems are prevalent in sixth grade. Youth averaged 96 minutes of physical activity per day in sixth grade, well above the recommended 60 minutes per day. In sixth grade, youth reported engaging in sedentary behavior for an average of 106 minutes per day, suggesting that, while youth are engaging in healthy levels of physical activity, they are also spending significant time in a sedentary state. Furthermore, time spent in physical activity varied significantly less than sedentary behavior. In 6th grade, minutes spent in moderate-to-vigorous activity had a standard deviation of 37.68 minutes, while the standard deviation for minutes spent in sedentary behavior was 94.98. This indicates that the time youth spend in sedentary behavior varies significantly, but the vast majority of youth are engaging in the recommended 60 minutes per day of physical activity, even if they are below the average in this sample. Average pubertal development was rated by the mother as low, indicating that many children had not started puberty, or were in the very early stages of puberty in sixth grade. Indeed, descriptive statistics reveal that only 9% of the sample were rated by their mother as being in advanced stages of puberty.

Correlations among the primary study variables can be found in Table 2. As expected, youth reported general sleep problems in 6th grade was negatively associated with all academic

outcomes in adolescence, with the exception of English self-concept (see Table 2). Thus, youth who reported more sleep problems in sixth grade demonstrated lower achievement at age 15 than did youth who reported fewer sleep problems. Physical activity in sixth grade was negatively correlated with Picture Vocabulary and English self-concept (see Table 2), suggesting that youth who spent more time engaged in moderate-to-vigorous activity also experience lower verbal comprehension scores and lower academic self-concept in English. Contrary to expectation, sedentary behavior in sixth grade was not significantly correlated with academic outcome variables. Physical activity in sixth grade was also negatively correlated with general sleep problems, indicating that more physical activity was related to fewer sleep problems. As expected, time spent in moderate-to-vigorous physical activity was significantly and negatively related to time spent in sedentary behavior at the same age, such that more time spent in physical activity was associated with less time spent in sedentary behavior. Moderator variables showed some significant correlations with academic outcome variables. For example, boys did significantly better on picture vocabulary and applied problems assessments at age 15, but had significantly lower self-concept in English than girls at the same age. This suggests that boys tend to do better on objective assessments of academic achievement than their female counterparts, but they experience lower self-concept in English (see Table 2).

Sleep, Physical Activity, and Achievement

Parameter estimates from the fitted structural equation models predicting changes in adolescent achievement across middle childhood and adolescence from sleep indicators in 6th grade is presented in Figure 1. After controlling for a range of child and family factors, as well as previous test scores, we found that self-reported general sleep problems in 6th grade was significantly associated with directly assessed picture vocabulary scores at age 15 ($B = -.132, p <$

0.05). Children who reported more general sleep problems in middle childhood experience greater declines in picture vocabulary indices across middle childhood and adolescence. Contrary to expectation, after controlling for earlier achievement scores, youth reported sleep problems was not significantly associated with changes in applied problems, English self-concept or math self-concept across middle childhood and adolescence. Child sex significantly predicted picture vocabulary and applied problems scores, as well as English self-concept at age 15. In other words, males scored higher on direct assessments of picture vocabulary and applied problems, but lower on indices of self-concept in English across middle childhood and adolescence. Similarly, maternal education was significantly and positively associated with all achievement outcomes except math self-concept, such that children whose mothers were more educated experienced fewer declines in indices of picture vocabulary, applied problems, and English self-concept across middle childhood and adolescence. No association was found between time spent in moderate-to-vigorous activity in 6th grade and any of the achievement outcomes across middle childhood and adolescence after controlling for child and family factors as well as previous test scores. Just as in the first model, child sex was a significant predictor of picture vocabulary and applied problems, as well as English self-concept at age 15. Maternal education was positively and significantly associated with changes in picture vocabulary, applied problems, and English self-concept scores, such that youth whose mothers were more educated experienced fewer declines on indices of picture vocabulary, applied problems, and self-concept in English across middle childhood and adolescence. Maternal education was also significantly associated with self-concept in Math in 6th grade, but not at age 15. Child sex significantly predicted time spent in moderate-to-vigorous activity in 6th grade, such that males spent more time engaged in moderate-to-vigorous activity than their female counterparts. Additionally,

sedentary behavior in 6th grade was significantly and negatively predictive of time spent in moderate-to-vigorous activity in 6th grade. Children who reported spending more time engaged in sedentary behavior in 6th grade were found to spend less time engaged in moderate-to-vigorous activity in 6th grade.

Moderators of Sleep Problems on Achievement

In order to investigate the potential moderating effects of physical activity on the relationship between sleep and achievement, we added to our models a series of two-way interactions between children's self-reported sleep problems in 6th grade and objectively measured time spent in physical activity in 6th grade, as well as children's self-reported sleep problems in 6th grade and children's self-reported sedentary behavior in 6th grade. After controlling for a range of individual and family factors, as well as previous scores, neither physical activity nor sedentary behavior were significant moderators of the relationship between sleep problems in 6th grade and changes in achievement across middle childhood and adolescence. In order to explore the relationship between sleep and achievement further, we fit models examining the moderating roles of sex and pubertal status in 6th grade on the relationship between sleep in middle childhood and changes in academic achievement across middle childhood and adolescence. Unexpectedly, there was again no evidence of moderation once we controlled for individual and family factors, as well as previous achievement scores. Given that there were no significant two-way interactions, we did not test the three-way interaction between sleep, physical activity, puberty, and child sex on directly assessed achievement and child self-reported academic self-concept.

CHAPTER 4: DISCUSSION

Recent research has documented normative declines in achievement, sleep and physical activity across middle childhood and adolescence (Colrain et al., 2011; McGill et al., 2012; Metcalf et al., 2015). As such, the current study sought to examine whether sleep and physical activity in middle childhood were associated with changes in a range of achievement outcomes across middle childhood and adolescence. Consistent with existing research indicating that sleep is related to academic outcomes (Bub et al., 2011; Curcio et al., 2006; Fredriksen et al., 2004), our study showed that sleep in middle childhood predicted changes in picture vocabulary skills between 5th and 10th grade. No other associations between sleep and changes in academic achievement or self-concept were identified. Contrary to expectation, physical activity and sedentary behavior were unrelated to changes in achievement and self-concept after accounting for child and family characteristics. Finally, we found no evidence to suggest that the associations between sleep and changes in achievement were moderated by physical activity or sedentary behavior, youth sex, or puberty. We discuss these findings in more detail below.

Sleep, Achievement, and Self Concept

Our findings are consistent with supplementary analyses reported in Touchette, Petit, Seguin, Boivin, Tremplay and Montplaisir (2007), but we extend their work, and the work of others (Clemens, Fabo & Halasz, 2005), by offering evidence that the links between sleep and changes in achievement across middle childhood and adolescence might be particularly salient for picture vocabulary skills. For example, Bub et al. (2011) found that second and third graders whose sleepiness levels increased at a steeper rate also reported significantly lower growth in verbal comprehension across a 3-year period. Similarly, Honaker, Gozal, Bennett, Capdevila

and Spruyt (2009) discovered that, while cognitive outcomes remained stable, sleep disordered breathing in young children was significantly associated with substandard verbal abilities (e.g., processing verbal instructions and verbal comprehension). These studies suggest that verbal comprehension skills may be particularly vulnerable to sleep problems across middle childhood and adolescence. Sleep might be especially salient for verbal comprehension skills due to its reliance on the pre-frontal cortex. Indeed, verbal comprehension is thought to function in the pre-frontal cortex (Narayanan, Prabhakaran, Bunge, Christoff, Fine, & Gabrieli, 2005; Westphal, Reggente, Ito, & Rissman, 2016), an area of the brain associated with sleep (Liu, Wang, Cai, Li, Chen, Dong, & Huang, 2016; Song, Scullin, & Park, 2016). The prefrontal cortex works to represent information not currently in the environment, where the formation of representational knowledge can guide thought, action, and emotion (Goldman-Rakic, 1996). Representational and conceptual knowledge is also a fundamental piece of verbal comprehension (Ralph, 2014). The prefrontal cortex is also thought to develop rapidly across middle childhood and early adolescence, such that pubertal development has been linked to maturation in the prefrontal cortex (Blakemore, 2010). Thus, this developmental period may be particularly salient for maturation of verbal comprehension skills in the prefrontal cortex. Indeed, a review by Durmer and Dinges (2005) found that sleep deprivation was related to neurocognitive disruptions in the pre-frontal cortex as well as declines in verbal skills. Although these studies do examine the adverse effects of sleep problems on verbal comprehension and crystallized intelligence long term, they fail to provide evidence for this relationship across middle childhood and adolescence, a gap we begin to address here.

Contrary to expectations, the current study revealed that sleep problems in 6th grade was not significantly associated with directly assessed applied problems across middle childhood and

adolescence. It is possible that sleep is related to memory through the pre-frontal cortex, which is subsequently related to math achievement. Indeed, research has shown that sleep impacts the functioning of the prefrontal cortex (Liu et al., 2016), which is particularly important for memory (Stokes, 2015). Memory, in turn, has been consistently considered an important factor for mathematics achievement across middle childhood and adolescence (Katz, 2017).

Contrary to expectation, we also observed that sleep problems in 6th grade were not significantly associated with self-concept in English and math across middle childhood and adolescence. This could be explained by the fact that self-awareness and self-concept are thought to be processed in the Anterior Insular Cortex (AIC) and the Anterior Cingulate Cortex (ACC), regions of the brain, which are related to experiential and behavioral phenomena (Craig & Craig, 2009; Medford & Critchley, 2010). The AIC is thought to integrate an awareness of cognitive, affective, and physical states, which are then re-represented in the ACC in order to select and prepare responses to these inner and outer events. Thus, the combined action of the AIC and the ACC provides the neural basis for self-awareness and self-concept (Medford et al., 2010). Indeed, fMRI scans have observed significant activation in the AIC and ACC during experiences of self-awareness or self-reflection (Devue, Collette, Balteau, Degueldre, Luxen, Maquet & Brédart, 2007; Modinos, Ormel & Aleman, 2009). Interestingly, research suggests that the AIC and ACC may be less impacted by sleep than other sections of the brain (Braun, Balkin, Wesenten, Carson, Varga, Baldwin, ... & Herscovitch, 1997). Thus, it may be that sleep is less related to self-concept across time since it is less salient for the brain regions that house self-concept. Another explanation for these findings could be methodological. For example, Structural Equation Modeling requires variability for it's sample, and the self-concept measures used in the current study do contain much variability, with youth averaging a score of 5.64 in

English self-concept and 5.14 in math self-concept on a scale of 7, and standard deviations ~ 1 for each measure. Thus, lack of variability in the self-concept measures used for the current study could be related to these non-significant findings.

Physical Activity, Sedentary Achievement, and Self Concept

Contrary to expectation, we observed that time spent in moderate-to-vigorous activity in 6th grade was not significantly related to changes in academic achievement across middle childhood and adolescence. This is similar to the findings of Ahamed et al. (2007), Coe et al. (2006) and Corder et al. (2015) who all found no association between physical activity and academic achievement. It may be that physical activity is not directly related to changes in academic achievement, but to cognitive processes that support academic achievement. For example, a comprehensive review by Donnelly et al. (2017) concluded that physical activity was significantly related to cognition, brain structure and activation of the prefrontal cortex, but not with academic achievement. Given the physiological benefits of physical activity on brain functioning and plasticity (Cotman & Berchtold, 2002), it could be that physical activity supports cognition, which in turn supports achievement, creating an indirect pathway between physical activity and achievement.

It may also be that physical activity is related to emotional development and attention or executive functioning (Etnier, & Chang, 2009; Mahar, 2011), which in turn supports achievement. Indeed, research has found that more time spent in physical activity during childhood and adolescence is associated with fewer depressive symptoms, feelings of hopelessness, as well as lower stress and higher levels of happiness (Moljord, Eriksen, Moksnes, & Espnes, 2011; Rothon, Edwards, Bhui, Viner, Taylor, & Stansfeld, 2010; Taliaferro, Rienzo, Miller, Pigg, & Dodd, 2008). Since a breadth of research has found significant associations

between emotions and academic achievement, with more positive emotions and better emotion regulation related to better academic achievement, this is significant (Durlak, Weissberg, Dymnicki, Taylor, & Schellinger, 2011; Trentacosta & Izard, 2007; Valiente, Swanson, & Eisenberg, 2012). Additionally, Hogan, Catalino, Mata and Fredrickson (2015) found that time spent in physical activity independently predicted emotions and psychosocial resources, and mediation analyses suggested that emotions may account for the relation between activity and psychosocial resources. In other words, emotions might mediate the relationship between physical activity and psychosocial resources. As such, future research examining these links might look at the role that physical activity might play in predicting emotions and subsequent achievement.

We observed that time spent in sedentary behavior in 6th grade was not significantly related to changes in achievement across middle childhood and adolescence. This is similar to the findings of Ohannessian (2009), and Skoric, Teo, and Neo (2009) where sedentary behavior, characterized by time spent using media, was not significantly associated with self-esteem and academic achievement. It may be that sedentary behavior is significantly related to health outcomes, which are subsequently related to achievement across middle childhood and adolescence. More time spent in sedentary behavior has consistently been linked to higher body mass index and obesity as well as poor dietary behaviors, (Kuzik & Carson, 2016; Sanchez, Alvaro, Norman, Sallis, Calfas, Cella and Patrick, 2007; Tremblay et al., 2011; Utter, Neumark-Sztainer, Jeffery, & Story, 2003), which are linked to lower achievement (Crosnoe, & Muller, 2004; Logi Kristjánsson, Sigfúsdóttir, & Allegrante, 2010). It is also plausible that sedentary behavior is significantly related to risky behaviors, such as substance use and abuse, delinquent behavior, etc., which are subsequently and negatively related to achievement. Indeed, sedentary

behavior has been linked to illegal drug use and greater engagement in violence (Nelson et al., 2006), both of which are related to lower achievement and dropping out of school (Wang & Fredricks, 2014). Skoric et al. (2009) found that, while time spent in sedentary behavior was not associated with scholastic achievement, it was associated with addiction tendencies; these addiction tendencies have been linked with poor achievement in other work (Musgrave-Marquart, Bromley, & Dalley, 1997). Additionally, Sharif, Willis and Sargent (2010) reported that screen exposure and screen time were indirectly associated with academic performance through substance use and sensation seeking. Thus, while sedentary behavior may not directly be related to academic achievement, they may be related to health outcomes and risk factors, which are subsequently related to achievement. Thus, as with physical activity, additional mechanisms linking sedentary behavior with achievement should be explored in future studies.

Moderating Effects of Physical Activity, Sex and Puberty

Contrary to expectations, we observed that time spent in moderate-to-vigorous activity in 6th grade did not significantly moderate the relationship between sleep in 6th grade and changes in academic achievement across middle childhood and adolescence. This could be because sleep and physical activity are not related (Youngstedt et al., 2003) or because physical activity is predictive of sleep, but sleep is not predictive of physical activity (Ekstedt et al., 2013). Since time spent in physical activity in middle childhood was not significantly related to changes in achievement across middle childhood and adolescence, it is less surprising that physical activity did not moderate the links between sleep in middle childhood and changes in achievement. One interesting thing to note is that study children in this sample engaged in a large quantity of physical activity. Thus, time spent in physical activity may not play the expected protective role, since most children in the sample engaging in more than sufficient levels of exercise.

Unexpectedly, we also found that sex did not significantly moderate the relationship between sleep in 6th grade and changes in achievement across middle childhood and adolescence. This is supported by the recent findings of Fuligni, Arruda, Krull, and Gonzales (2018), as well as Martin, Gaudreault, Perron, & Laberge (2016), who noted that the associations between sleep duration and achievement did not significantly vary across gender. It could be that sex is not as salient for sleep in 6th grade, but is related to sleep trajectories across development, which in turn, impact changes in achievement across middle childhood and adolescence. Indeed, girls report a steeper decline in sleep across middle school than their male counterparts (Fredriksen et al., 2004), and sleep patterns across development have been significantly associated with test scores over time (Eide & Showalter, 2012). Thus, it could be that sex is a particularly important moderator in the changes of sleep and achievement across development.

Similar to the findings of Erath, Tu, Buckhalt, and El-Sheikh (2015), we also observed that pubertal development in 6th grade did not significantly moderate the relationship between sleep problems in 6th grade and changes in achievement across middle childhood and adolescence. This could be explained by the lack of variability in pubertal development in our sample, with most mothers reporting low levels of pubertal development, or no pubertal development at all in study children. It is also possible that the interaction between sleep and pubertal development might be indirectly related to achievement through achievement related behaviors. Indeed, more advanced stages of pubertal development and sleep have been linked to falling asleep in school or while doing homework (National Sleep Foundation, 2006) and declines in achievement motivation (Martin et al., 2017), important factors for academic achievement. For example, Dahl and Lewin (2002) suggest that adolescents experiencing a circadian rhythm shift in sleep due to the onset of puberty go to bed later but wake up at school

time, resulting in falling asleep in class, difficulty paying attention and greater emotional stress, which could significantly impact academic achievement. Thus, it could be that the moderation of pubertal status might be particularly salient for indices of achievement like academic motivation, attention, or working memory, rather than achievement itself.

Limitations and Future Directions

The results and conclusions drawn from this work must be considered in the context of the study's limitations. First, sleep was measured through self-reported measures completed by the study child. Although self-reported measures of sleep have shown sufficient reliability and validity, objective measures of sleep (e.g., actigraphy and accelerometers) more accurately capture multiple dimensions of sleep than do subjective measures. However, large scale datasets typically use parent or self-reported measures of sleep due to cost and time constraints.

Importantly, despite the fact that findings from self-report and objective measures of sleep are often inconsistent, previous research has shown that different sleep measurement methods offer distinctive and justifiable sleep data (Sadeh, 2008). Future studies should combine both objective and subjective measures of sleep to provide a comprehensive evaluation of sleep. It may be that objectively measured sleep is particularly important during this transitional life-stage, where youth shift from a morningness to an eveningness preference (Coelho et al., 2017).

Second, despite the participants being representative of the catchment areas from which they were recruited in 1991, the sample is not considered nationally representative, and our findings cannot be generalized to the wider population. Given that poor sleep and low physical activity are more prevalent among ethnic minority and low-income individuals (Wong, Ortiz, Lathan, Moore, Konzelmann, Adolph, ... & Butte, 2013), future research should attempt to recruit a nationally representative sample to understand these processes in the population. Third,

the current study made use of an existing dataset. Although secondary data analysis allows us to utilize a large sample with longitudinal data, the original study was not designed to address the questions posed in the current study. As such, the measures available for addressing our research questions were limited, thereby restricting our understanding of the role of sleep to subjective measures and measures taken at few time points. For example, in this dataset, sleep and physical activity were measured at two time points across middle childhood and adolescence, preventing an examination of sleep, physical activity and academic achievement trajectories over time. Thus, future research should seek to collect sleep data at multiple time points in order to fully understand how sleep, physical activity and academic achievement develop.

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APPENDIX A: TABLE 1

Descriptive Statistics on Outcome and Key Predictor Variables for the Fully Analytic Sample by Age of Assessment				
	Other ages Mean (SD)	5 th Grade Mean (SD)	6 th Grade Mean (SD)	15 Years Mean (SD)
<i>Academic Outcome Variables</i>				
Picture Vocabulary	-	103.24(14.61)	-	99.98(14.56)
Applied Problems	-	109.42(13.21)	-	103.00(14.13)
Self Concept in English	-	-	5.88(.99)	5.64(1.07)
Self Concept in Math	-	-	5.79(1.00)	5.14(1.18)
<i>Sleep Variables</i>				
General Sleep Problems Self Concept	-	-	19.52(5.09)	-
<i>Physical Activity Variables</i>				
Moderate-to-Vigorous Activity	-	-	96.24(37.68)	-
Sedentary Behavior Activity	-	-	106.92(94.98)	-
<i>Moderator Variables</i>				
Pubertal Status	-	-	.10(.30)	-
Male	.50(.50)	-	-	-
<i>Control Variables</i>				
ADHD	-	-	13.14(.30)	-
BMI_Z Score	-	-	.51(1.11)	-
Income-to-Needs	-	4.53(4.06)	4.60(4.22)	5.27(5.81)
African American	.12(.33)	-	-	-
European American	.81(.39)	-	-	-
Mother's Education	14.45(2.45)	-	-	-

APPENDIX B: TABLE 2

	1	2	3	4	5	6	7	8	9
1. Applied Problems (15)	--								
2. Picture Vocabulary (15)	.58**	--							
3. English Self-concept (15)	.09**	.15**	--						
4. Math Self-concept (15)	.27**	.03	.13**	--					
5. General Sleep Problems (G6)	-.10**	-.10**	-.05	-.09**	--				
6. Physical Activity (G6)	-.00	-.08*	-.12**	.04	-.09*	--			
7. Sedentary Behavior (G6)	-.03	.00	-.02	-.00	.05	-.08	--		
8. Sex	.10**	.12**	-.22**	.05	.00	.27**	.15**	--	
9. Pubertal Status (G6)	-.07*	-.11**	.08*	-.05	.02	-.13**	.02	-.29**	--

** . Correlation is significant at the 0.01 level (2-tailed).

APPENDIX C: FIGURE 1

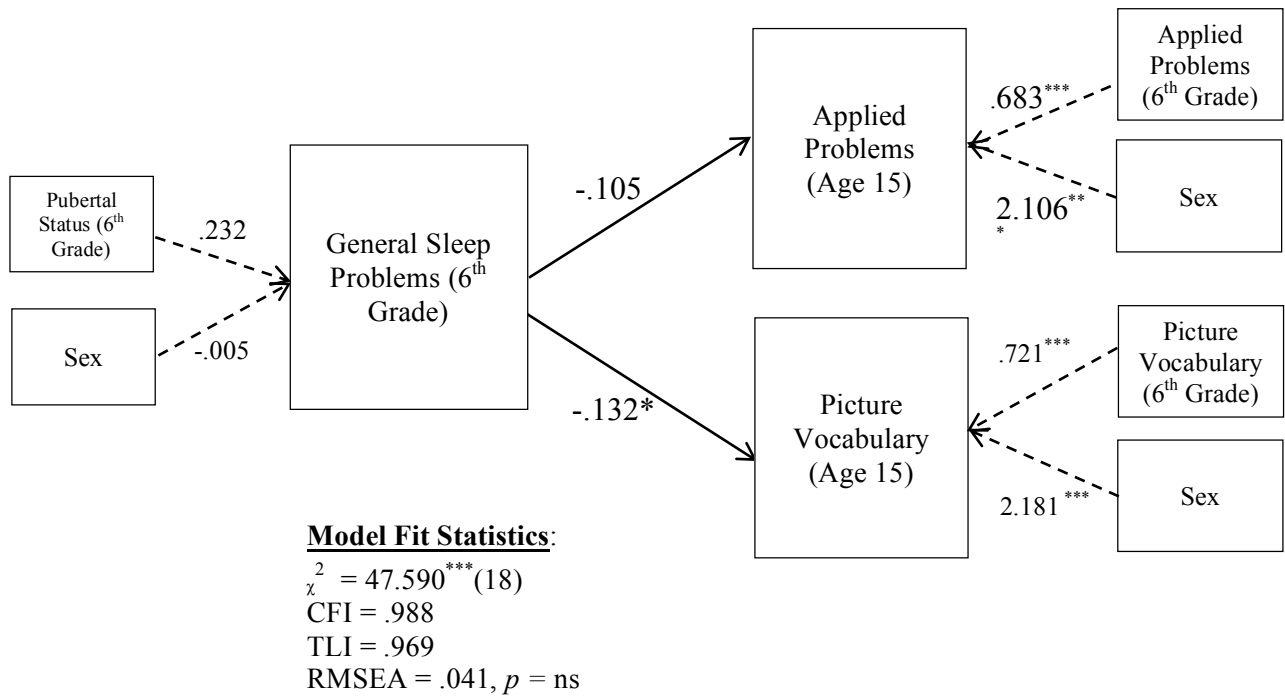


Figure 1. Structural equation models depicting the associations between general sleep problems in 6th grade and changes in directly assessed achievement across middle childhood and adolescence. Model includes the following controls on general sleep problems: Male ($B = -.005$), Body Mass Index in 6th grade ($B = .133$), European American ($B = -.454$), Pubertal Status in 6th grade ($B = .232$), income-to-needs in 5th grade ($B = -.073$). Model includes the following controls on directly assessed picture vocabulary achievement at age 15: Male ($B = 2.181^{***}$), European American ($B = 2.664^{***}$), income-to-needs at age 15 ($B = .078$), previous picture vocabulary test score in 5th grade ($B = .721^{***}$), and maternal education ($B = .592^{***}$). Model includes the following controls on directly assessed applied problems test score at age 15: Male ($B = 2.106^{**}$), European American ($B = 1.064$), income-to-needs at age 15 ($B = .173^{**}$), previous applied problems test score at 5th grade ($B = .683^{***}$), and maternal education ($B = .766^{***}$).
 $^{***} p < .001$, $^{**} p < .01$, $^* p < .05$

APPENDIX D: FIGURE 2

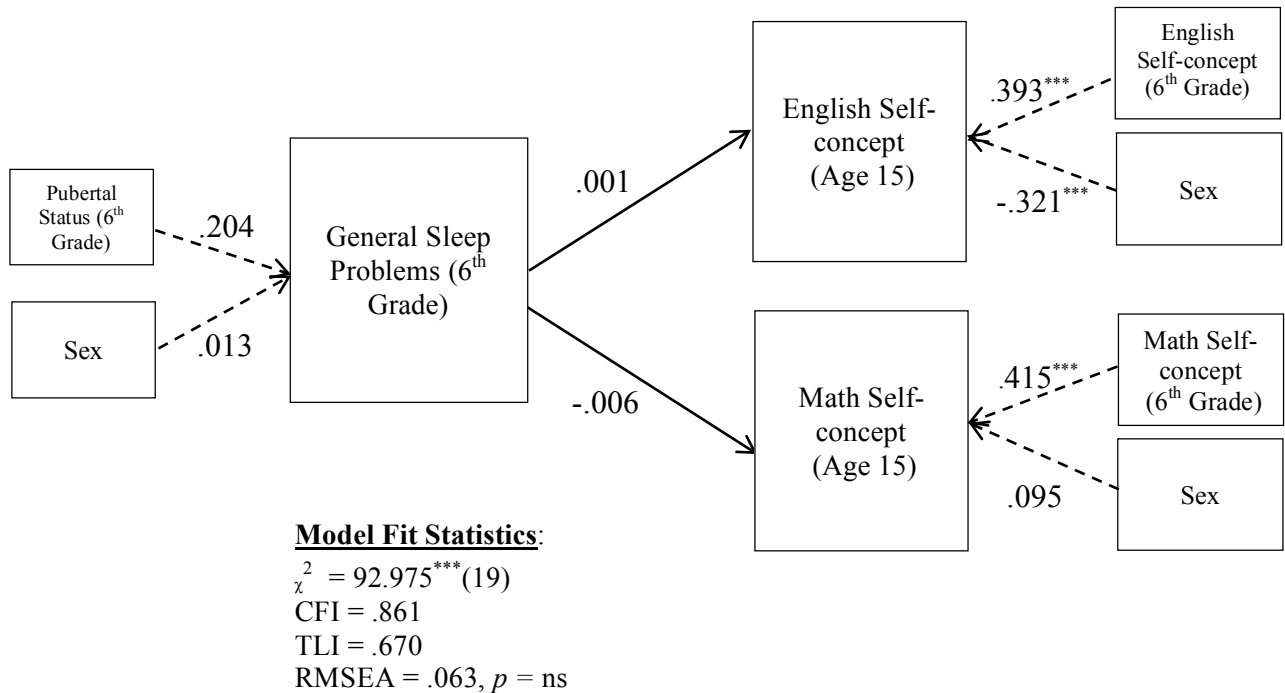


Figure 2. Structural equation models depicting the associations between general sleep problems in 6th grade and changes in English and math self-concept across middle childhood and adolescence. Models include the following controls on general sleep problems: Male ($B = .013$), Body Mass Index in 6th grade ($B = .159$), European American ($B = -.531$), Pubertal Status in 6th grade ($B = .205$), and income-to-needs in 6th grade ($B = -.040$). Models include the following controls on self-concept in Math at age 15: Male ($B = .095$), European American ($B = -.128$), Math self-concept score in 6th grade ($B = .415^{***}$), maternal education ($B = -.007$), and income-to-needs at age 15 ($B = .009$). Models include the following controls on self-concept in English at age 15: Male ($B = -.321^{***}$), European American ($B = -.088$), income-to-needs at age 15 ($B = .001$), English self-concept at 6th grade ($B = .393^{***}$), and maternal education ($B = .029^*$).

*** $p < .001$, ** $p < .01$, * $p < .05$

APPENDIX E: FIGURE 3

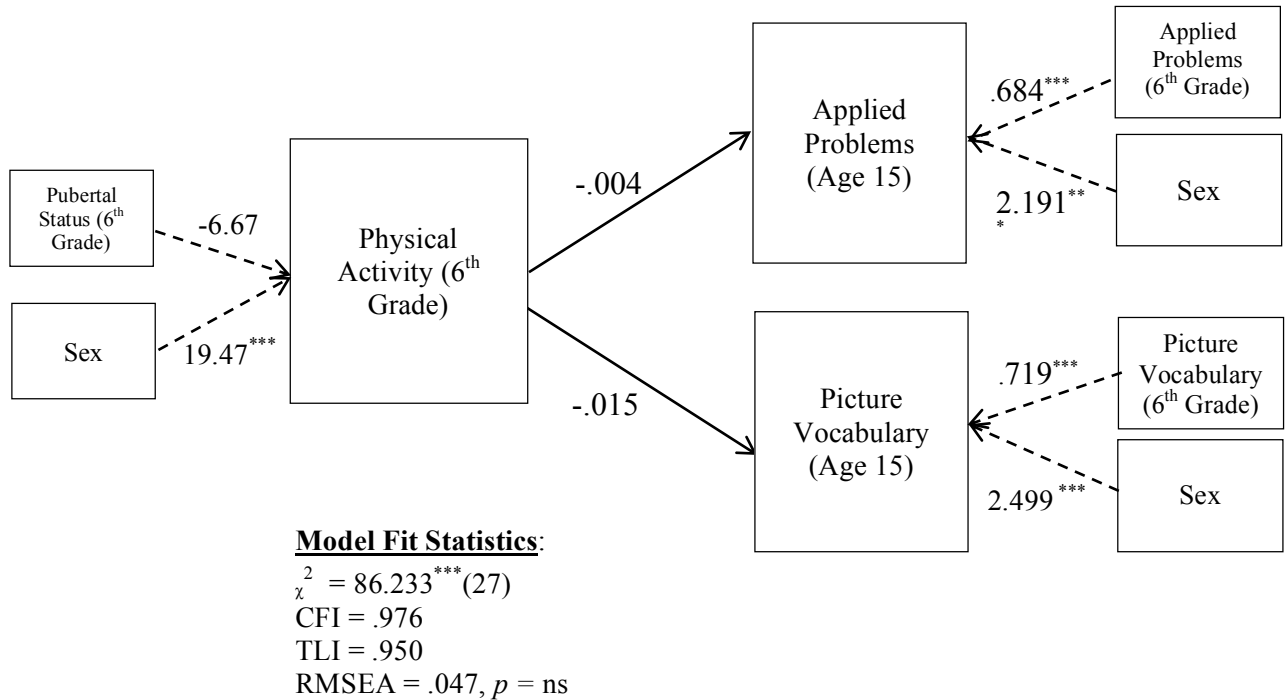


Figure 3. Structural equation models depicting the associations between time spent in moderate-to-vigorous activity in 6th grade and changes in directly assessed achievement across middle childhood and adolescence. Model includes the following controls on time spent in moderate-to-vigorous physical activity in 6th grade: Male ($B = 19.468^{***}$), European American ($B = -1.521$), ADHD symptoms in 5th grade ($B = .226$), sedentary behavior in 6th grade ($B = -.045^*$), and pubertal status in 6th grade ($B = -6.668$). Model includes the following controls on directly assessed picture vocabulary at age 15: Male ($B = 2.499^{***}$), European American ($B = 2.714^{***}$), income-to-needs at age 15 ($B = .079$), previous picture vocabulary test scores at 5th grade ($B = .719^{***}$), and maternal education ($B = .610^{***}$). Model includes the following controls on directly assessed applied problems at age 15: Male ($B = 2.191^{**}$), European American ($B = 1.090$), income-to-needs at age 15 ($B = .176^{**}$), previous applied problems test scores at 5th grade ($B = (.684^{***})$, and maternal education ($B = .776^{***}$).

*** $p < .001$, ** $p < .01$, * $p < .05$

APPENDIX F: FIGURE 4

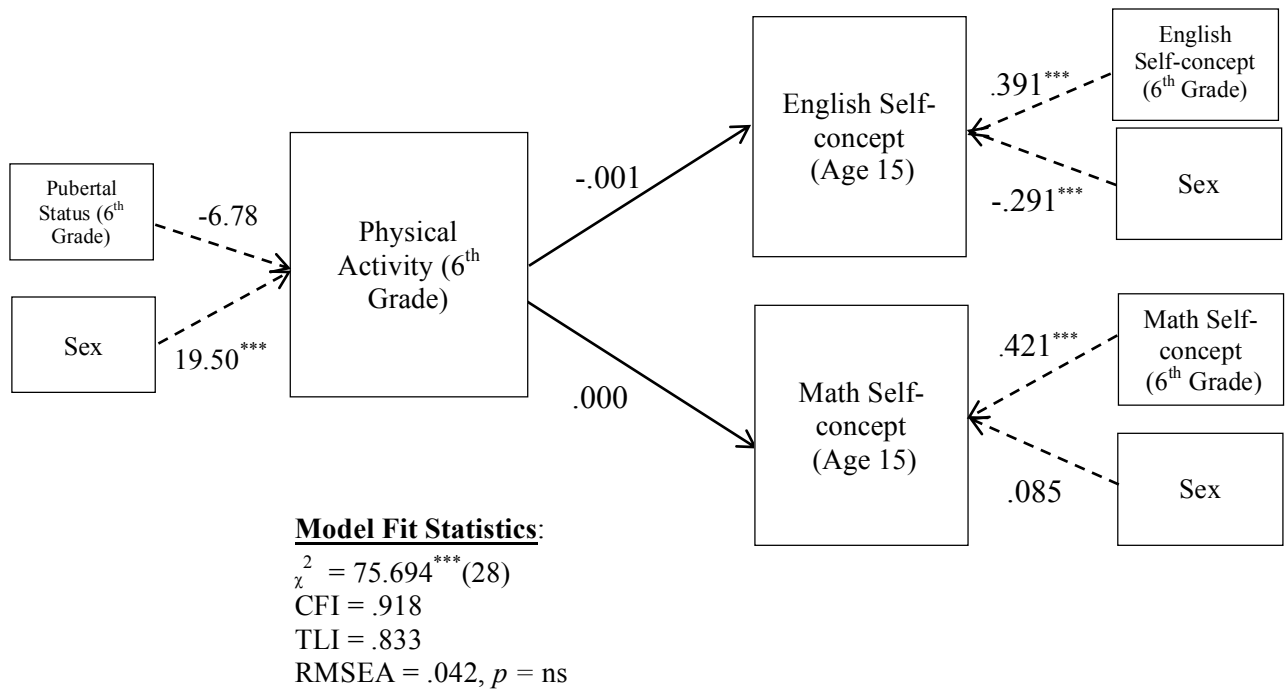


Figure 4. Structural equation models depicting the associations between time spent in moderate-to-vigorous activity in 6th grade and changes in English and math self-concept across middle childhood and adolescence. Models include the following controls on time spent in moderate-to-vigorous activity: Male ($B = 19.503^{***}$), European American ($B = -1.267$), ADHD symptoms in 5th grade ($B = .212$), sedentary behavior in 6th grade ($B = -.046^{**}$) and pubertal status in 6th grade ($B = -6.785$). Model include the following controls on self-concept in English at age 15: Male ($B = -.291^{***}$), European American ($B = -.089$), income-to-needs at age 15 ($B = .000$), previous English self-concept score at 6th grade ($B = .392^{***}$), and maternal education ($B = .029^*$). Models include the following controls on self-concept in Math at age 15: Male ($B = .086$), European American ($B = -.125$), income-to-needs at age 15 ($B = .009$), previous math self-concept score ($B = .421^{***}$), and maternal education ($B = -.006$).

*** $p < .001$, ** $p < .01$, * $p < .05$