THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF PSYCHOLOGY

INHERITED AND ENVIRONMENTAL INFLUENCES ON CHILD PHYSICAL ACTIVITY: AN ADOPTION STUDY

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SUMMER 2017

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Psychology
with honors in Psychology

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ABSTRACT

Child physical activity plays an important role in decreasing risk for obesity, preventing health issues, and improving mental well-being. Both the family environment and heritable factors influence physical activity in childhood; however, few genetically-informed designs have examined the unique contributions of inherited and environmental influences and the interplay between these influences on child physical activity. Using a longitudinal adoption design, the present study examined the inherited (birth mother body mass index [BMI] and physical activity) and environmental (adoptive parent [AP1 and AP2] role modeling and logistical support) influences, as well as environmental moderation effects, on adopted child physical activity at age 9 years (N = 361). At 5 months postpartum, birth mother BMI was assessed using self-reported height and weight. When children were age 9 years, AP role modeling/logistical support of child physical activity was assessed using the Parent Activity Support Scale, and adopted child physical activity was assessed with parent report using a 3-day activity recall. Results showed that birth mother physical activity and AP1 logistical support were significantly associated with adopted child physical activity. Additionally, AP2 logistical support moderated the heritable influence of birth mother physical activity such that at high levels of AP2 logistical support, adopted children of high physical activity birth mothers engaged in higher levels of physical activity compared to adopted children of low physical activity birth mothers. These findings support the influence of inherited and environmental factors on child physical activity and suggest that supportive parenting practices may promote the expression of children's inherited tendency for physical activity.

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ACKNOWLEDGEMENTS

First and foremost, I would like to extend my gratitude to the biological parents, adoptive parents, and adopted children who have participated in the Early Growth and Development Study. Without your willingness to provide personal information and engage with researchers, this study, and the important findings that have emerged from this study, would be nonexistent. I would also like to thank the Early Growth and Development Study team for graciously allowing me to use their data as the basis for my project. Additionally, I would like to thank my thesis supervisor, Dr. Jenae Neiderhiser, whose expertise, support, and patience guided this project through to completion and whose research allowed me to explore my interest in gene-environment interplay. I am forever grateful to you for sharing your experience, time, and knowledge with me. Finally, I would like to thank Amanda Ramos, an Early Growth and Development Study graduate research assistant, who worked with me on the front lines of this project, tirelessly answering questions, assisting with tasks from concept development to running analyses, and always ensuring that understanding was the foundation upon which I built this project.

Introduction

Childhood obesity is a public health crisis that can have detrimental effects on short- and long-term health including increased risk of cardiovascular disease, type II diabetes, respiratory abnormalities, and psychological problems (Ebbeling, Pawlak & Ludwig, 2002; Faith & Kerns, 2005; Karnik & Kanekar, 2012; Reilly et al., 2003). According to the Center for Disease Control and Prevention, childhood obesity, "defined by an excess of body fat" (Després, 2012), has more than doubled among 6- to 11-year olds (7 to 17.5%) and quadrupled among 12- to 19-year olds (5 to 20.5%) since the 1980s (Segal, Rayburn, & Martin, 2015). In the absence of intervention or drastic lifestyle change, childhood obesity often persists into adulthood (~77%) with potential detrimental outcomes (e.g., stroke and heart disease; Freedman, Kettel-Khan, Dietz, Srinivasan, & Berenson, 2001; Reilly et al., 2003). Since obesity fundamentally results from an imbalance in energy intake (calories consumed) and energy expenditure (calories burned) (National Institutes of Health, 2007), increasing energy expenditure through increased moderate-vigorous physical activity can reduce the risk of developing obesity, chronic illness, and psychological issues (Janssen & LeBlanc, 2010; Sothern, Loftin, Suskind, Udall, & Blecker, 1999). Research on increasing moderate-vigorous physical activity and reducing sedentary time has found that these behavioral interventions are more effective in middle childhood (approximately ages 6 – 11 years; Papalia & Feldman, 2011) than in adolescence (Danielsson, Kowalski, Ekblom, & Marcus, 2012). In order to create intervention programs tailored to this developmental period, we must understand what factors impact physical activity during middle childhood specifically.

Research suggests that engagement in physical activity in early/middle childhood is often shaped by family environments (Moore et al., 1991; Oliver, Schofield, & Schluter, 2010). However, there is also considerable evidence to suggest that physical activity is influenced by heritable factors related to body mass index (BMI) and physical activity level (Wood, Saudino, Rogers, Asherson, & Kuntsu, 2007; Saudino & Zapfe, 2008). In order to gain a comprehensive understanding of physical activity in middle childhood, it is imperative to examine both inherited and environmental influences on child physical activity. Utilizing a genetically-informed research design allows us to examine the unique effect of inherited and environmental influences as well as the interplay between these influences. A firm understanding of how these influences shape physical activity can help to optimize the effectiveness of intervention programs for at-risk families (Moore et al., 1991).

The Influence of Parent Characteristics & Behavior

Parent characteristics, such as BMI, play a prominent role in shaping children's physical activity (Klesges, Eck, Hanson, Haddock, & Klesges, 1990; Finn, Johannsen, & Specker, 2002). Research has found that parent BMI is negatively associated with child physical activity (Griffiths & Payne, 1976; Klesges et al., 1990; Finn et al., 2002). Children (ages 3-6) of obese parents tend to be less physically active than children of non-obese parents and as the number of obese parents within a family increases, child physical activity decreases (Griffiths & Payne, 1976; Klesges et al., 1990). However, there have been some inconsistencies in these findings such that among a sample of 4-6-year-olds, there was no significant effect of parental BMI on infant/child energy expenditure (Davies, Wells, Fieldhouse, Day, & Lucas, 1995; Goran et al., 1995).

Parent behavior, such as physical activity, also influences child physical activity (Moore et al., 1991; Oliver et al., 2010). Evidence suggests that parent physical activity is modestly to moderately associated with child physical activity in early and middle childhood (Moore et al., 1991; Oliver et al., 2010; Hesketh et al., 2014; Fogelholm, Nuutinen, Pasanen, Myohanen, & Saatela, 1999; Jago, Fox, Page, Brockman, & Thompson, 2010). A study by Moore et al. (1991) found that, during early/middle childhood, children of active mothers were twice as likely to be active compared to children of inactive mothers, and children of active fathers were 3.5 times as likely to be active compared to children of inactive fathers. However, evidence for the association between parent and child physical activity are somewhat mixed, with some studies finding positive relationships between parent and child physical activity and others finding nonsignificant associations (Sallis, Prochaska, & Taylor, 2000).

This lack of consistency in findings for both the influence of parent BMI and parent physical activity on child physical activity could stem from the fact that most of the reviewed studies assume that these associations are due to purely environmental influences (Moore et al., 1991; Oliver et al., 2010; Hesketh et al., 2014). However, because these studies examined biological parents rearing their biological child(ren), they are incapable of determining whether similarity in parent BMI/parent physical activity and child physical activity is due to heritable influences, environmental influences, or some combination of the two. Therefore, it is unclear as to whether parent BMI/parent physical activity influences child physical activity through the transmission of a heritable characteristic, aspects of the rearing environment (e.g. role modeling physical activity or providing opportunities for child physical activity) that the parents have created, or both.

Disentangling Inherited & Rearing Environment Influences

Using a parent-offspring adoption design allows us to disentangle heritable influences from those of the rearing environment, clarifying the extent to which similarities among family members are due to inheritance or rearing environment. As Knopik and colleagues (2017) note, parents raising their biological children are “genetic-plus-environment” parents, but placing a child into a novel family environment through adoption results in distinct “genetic” parents and “environmental” parents. The influence of the adoptive parents is limited to the shared family environment and when the adoption placement occurs at or near birth, the influence of the biological parents is limited to the transmission of genes. Consequently, similarities observed between the child and biological parents are influenced by genetics and similarities observed between the child and adoptive parents are influenced by the environment (Knopik, Neiderhiser, DeFries, & Plomin, 2017). This disentangling of heritable and environmental factors is essential for detecting gene-environment interactions. Environmental influences may interact with heritable influences to strengthen or protect against heritable risk factors and increase the likelihood of positive developmental outcomes. Thus, genetically-informed designs are essential to gaining a deeper understanding of environmental influences as well as gene-environment interplay and its influence on outcomes such as child physical activity.

BMI & Physical Activity as Genetic Influences

Several genetically-informed studies have found that BMI is heritable and influences child physical activity in early and middle childhood (Wardle, Carnell, Haworth, & Plomin, 2008; Haworth et al., 2008; Remmers et al., 2014). In a twin study examining heritable influences on waist circumference and BMI in 8 to 11-year-old children, BMI was highly heritable (77%), while shared environmental effects were low (10%) (Wardle et al., 2008). Additional longitudinal studies have found that BMI becomes more heritable from early childhood through middle childhood and early adolescence (Maes, Neale, & Eaves, 1997; Koeppen-Schomerus, Wardle, & Plomin, 2001 & Wardle et al., 2008), with one study finding heritability increasing from 48% to 78% from 4 to 11 years old (Haworth et al., 2008). Research has also shown that throughout childhood (5-9 years), BMI is related to moderate-vigorous physical activity (Remmers et al., 2014). Remmers et al. (2014) specifically found that, across time, decreases in BMI in more overweight (75th percentile of sample) boys and girls, and in normal weight (25th percentile of sample) boys, is related to increased moderate-vigorous physical activity. Therefore, BMI is a notable, heritable influence on physical activity during early/middle childhood.

There has also been consistent empirical support for the heritability of physical activity (Saudino & Zapfe, 2008; Wood et al., 2007). In a sample of 2-year-old twins, heritability of physical activity (measured as activity level) was found to be significant across three contexts (i.e. home, laboratory test, and laboratory play situations) (Saudino & Zapfe, 2008). Wood et al. (2007) examined objectively-assessed physical activity (measured as activity level) across two situations - a laboratory-based test and unstructured play - in a sample of 7-9-year old twin pairs. Physical activity correlations were stronger among monozygotic than dizygotic pairs, suggesting heritability, and twin analyses found that 36% of the variation in overall activity score was due to heritable influences. These findings support that individuals have an inherited tendency to be more or less active. While this research underlines the contribution of heritable influences on physical activity, physical activity phenotypes are malleable and may be modified by the environment (Franks et al., 2005). Using a genetically-informed design will allow us to determine the extent of heritable influence on physical activity in middle childhood, and the extent to which the environment functions to shape physical activity. Additionally, it provides a means to examine how inherited characteristics and the environment interact to influence physical activity.

Parental Role Modeling & Support as Environmental Influences

In addition to heritable influences on physical activity, there are distinct features of the rearing environment that may enhance children's propensity to be physically active. One such feature is parental role modeling (Vander Ploeg, Maximova, Kuhle, Simen-Kapeu, & Veugelers, 2012; Heitzler, Martin, Duke, & Huhman, 2006; Gustafson & Rhodes, 2006). Parental role modeling involves parents' efforts and desires to be physically active and to model physical activity for their children (Welk, Wood, & Morss, 2003). Parents encourage and set standards for activity through their own behavior that children observe and learn to emulate (Bois, Sarrazin, Brustad, Trouilloud, & Cury, 2005). In a study examining girls' perceptions of parents' physical activity, Madsen, McCulloch, & Crawford (2008) reported that girls who perceived that their parents exercised 3 or more times per week were, on average, 50% more active than girls who perceived their parents to be less active. These findings suggest that parental modeling of physical activity may be an effective tool for promoting physical activity among children.

Parental logistical support, encompassing such behaviors as providing access to and resources for physical activity opportunities, is another salient environmental feature that can affect child physical activity (Welk et al., 2003). Children are typically reliant on parents to enroll them in sports, transport them to activities, and fund activity-related expenses. Because parents function as "gatekeepers" to opportunities for activity, parental logistical support may play a key role in increasing child physical activity (Welk et al., 2003; Oliver et al., 2010). In fact, parents' logistical support and children's perceptions of parental logistical support (e.g. assurance of parental permission to enroll in activities that they desire) are both positively associated with children's physical activity (Gustafson & Rhodes, 2006; Heitzler et al., 2006). Research has also found that parental logistical support is most successful in promoting physical activity during early and middle childhood (Gustafson & Rhodes, 2006). Therefore, ensuring parental logistical support in middle childhood is critical for improving access to physical activity opportunities and, consequently, increasing child physical activity.

Some of the relevant literature has found that mothers and fathers may favor different parental behaviors for engaging their children in physical activity (Davison, Cutting, & Birch, 2003; Bois et al., 2005). Davison et al. (2003) examined the relationship between activity-related parenting behaviors (i.e. explicit modeling and logistical support) and child physical activity among 9-year-old girls and their parents. Fathers reported significantly higher levels of explicit modeling, while mothers reported significantly higher levels of logistical support, suggesting that there may be parental gender effects on the type of parental behavior used to promote child physical activity. However, both types of support (i.e. fathers' explicit modeling and mothers' logistical support) were associated with higher levels of child physical activity. In contrast to these findings, multiple studies have found that mothers' role modeling has more of an impact on child physical activity than fathers' role modeling in middle childhood (Bois et al., 2005; Power & Woolger, 1994; Sallis, Patterson, Buono, Atkins, & Nader, 1988). Fathers more successfully influenced their children's physical activity through other processes including their perceptions of their child's physical competence (Bois et al., 2005). This research highlights the potential differential effects of parent behavior on children's physical activity and the importance of considering the separate impact of each parent's behaviors on physical activity.

Environmental Moderation of Inherited Influences

In addition to directly influencing child physical activity, parental behaviors are effective at buffering against obesity risk (Klesges et al., 1990). In a study conducted by Klesges et al. (1990), researchers found that there was a significant interaction between the level of parental obesity and parental participation in children's activities in predicting child physical activity. Specifically, when there were low levels of parental participation, children at low risk for obesity (i.e. neither parent was obese) engaged in more physical activity. In contrast, at high levels of parental participation, children at high risk (i.e. both parents were obese) engaged in more physical activity, followed by children at moderate-risk (i.e. one parent was obese). Therefore, creating an environment that encourages and supports physical activity through parental participation, role modeling, and logistical support may increase physical activity among at-risk children and reduce the likelihood of these children becoming obese.

While the Klesges et al. (1990) study is important for understanding how parental obesity and parental participation interact to influence child physical activity, research examining both environmental and heritable influences on child physical activity is needed. One study, using a genetically-informed design, examined the effect that physical activity had on the heritable effects of BMI (Mustelin, Silventoinen, Pietilainen, Rissanen & Kaprio, 2009). Among 22- to 27-year-old twins, physical activity significantly moderated heritable effects on BMI, such that the impact of heritable factors decreased as physical activity increased. Thus, high levels of physical activity protected against inherited risk for obesity in early adulthood, prompting the need to investigate these effects at earlier ages.

Current Study

To our knowledge, there have been no genetically-informed studies conducted that examine the moderating effects of the rearing environment on inherited characteristics in middle childhood. The research questions addressed in the current study will help to fill this gap in the literature by using a genetically-informed design to examine whether adoptive parent behaviors (i.e. role modeling and logistical support) serve as a buffer against inherited risks (e.g. high BMI and low physical activity) through promoting physical activity in middle childhood. The purpose of the present study is to investigate the inherited (birth mother [BM] BMI and physical activity) and environmental (adoptive parent [AP1 and AP2] modeling/logistical support) influences on child physical activity at age 9 years with a longitudinal adoption design (Early Growth and Development Study: EGDS, Leve et al., 2013). This design allows us to disentangle the inherited and rearing environmental influences on child physical activity. We will examine whether BM

BMI, BM physical activity, and AP1 and AP2 modeling/logistical support are associated with adopted child (AC) physical activity, and whether AP1 and AP2 modeling/logistical support moderate the inherited influence from BM on AC physical activity. BM BMI was examined as a marker of inherited risk for AC physical activity (i.e. high BM BMI associated with high AC BMI and low AC physical activity) because BM BMI and AC physical activity are both indices of overall physical fitness. While previous research has examined mother and father parental role modeling and support behaviors, we elected to classify adoptive parents as AP1 and AP2, as opposed to mother and father, in order to retain data from our same-sex couples in analyses.

We will address the following four hypotheses as depicted in Figure 1: 1) BM BMI will be negatively associated with AC physical activity. 2) BM physical activity will be positively associated with AC physical activity. 3) AP1/AP2 role modeling and logistical support will be positively associated with AC physical activity. 4) AP role modeling and logistical support will moderate inherited risk. More specifically, we expect that when AP modeling/logistical support is low, children of low BMI and high physical activity BM will engage in significantly more physical activity than children of high BMI and low physical activity BM. However, when AP modeling/logistical support is high, children will engage in relatively high levels of physical activity regardless of their BM BMI and BM physical activity group because the rearing environment will buffer against inherited risk among the high BMI/low physical activity BM children. We will be examining AP1 and AP2 role modeling and logistical support separately; however, because we are not qualifying adoptive parents based on gender or otherwise, we do not hypothesize specific outcomes for how AP1 and AP2 role modeling and logistical support will separately influence child physical activity.

Method

Participants & Procedure

The present study used data from the Early Growth and Development Study (EGDS), a longitudinal adoption study that examines the influence of gene-environment interplay on child development outcomes from infancy to early adolescence (Leve et al., 2013). Participants were recruited in two cohorts between 2003 and 2010 through 45 adoption agencies across 15 states. The current study sample uses Cohort I which consists of 361 linked sets of adoptive families (i.e. adopted child, adoptive parents, and birth parents). Eligibility for the study was based on the following inclusion criteria: (a) the adoption placement was domestic, (b) placement occurred within 3 months of the child's birth (Cohort I: *M* = 7.11 days, *SD* = 13.28 days, *Mdn* = 2 days), (c) there was no biological relation between the adopted child and adoptive family, (d) the child had no known serious health conditions, and (e) both sets of parents understood English at the 8^{th}-grade level.

The children in the sample were 57.3% male. Additional demographic information on adopted children, birth mothers and adoptive parents is presented in Table 1. Birth parents, adoptive parents, and adopted children were assessed in-person, online, and through phone interviews using questionnaire measures and video-recorded observations. In the present study, data from the physical health, adult physical activity, parent activity support, and child physical activity assessments of birth mothers and adoptive families were used. Additional information about the EGDS study can be found in Leve et al. (2013).

Measures

Birth mother BMI. Birth mother height and weight data were collected by self-report at 5 months postpartum. BMI scores were subsequently calculated from the height and weight data (BMI = weight (lb) / [height (in)]^2 x 703).

Birth mother physical activity. Birth mother physical activity was assessed using self-report on the Adult Physical Activity scale (Krahnstoever Davison, Francis, & Birch, 2005) when children were age 9 years. This 15-item scale is a modified version of Tucker's Children's Physical Activity scale (Tucker, Seljaas, & Hager, 1997), designed to assess adult's feelings toward and participation in physical activity (Cronbach alpha AP1 $\alpha = 0.81$, AP2 $\alpha = 0.85$). Birth mothers were asked to respond to statements such as "I do activities that involve running, swimming or skating almost every day" and "I watch 3 or more TV programs most every day" on a 4-point Likert scale (from (1) "Completely True" to (4) "Completely False"). Higher scores indicate higher levels of reported physical activity.

Adoptive parent role modeling and logistical support. Role modeling and logistical support for both adoptive parents were assessed using self-reports on the Parent Activity Support Scale when children were age 9 years (Krahnstoever, 2004; Krahnstoever, Cutting, & Birch, 2003). The Parent Activity Support Scale consists of 7-items on a 4-point likert scale (from (1) "Strongly Disagree" to (4) "Strongly Agree"; Cronbach alpha AP1 $\alpha = 0.81$, AP2 $\alpha = 0.85$). Adoptive parents were asked to rate their agreement with 4-items related to role modeling such as "I use my behavior to encourage my child to be physically active" and 3-items related to logistical support such as "I enroll my child in sports and other physical activities (e.g. dance, hiking club)." Higher scores indicate higher levels of role modeling and logistical support.

Adopted child physical activity. Child physical activity was assessed when children were age 9 years using parent reports of their child's activity. Parents reported the number of hours their children engaged in moderate-intensity and high-intensity physical activity over a 24-hour period. Physical activity data was collected on 3 different days, within a 2-week period for most children. From these reports, we constructed an average total physical activity score by averaging hours spent in moderate- and high-intensity physical activity over the 3-day period.

Covariates. We included age of both adoptive parents at child birth, openness of adoption, sex of the child, and BM obstetric complications as covariates. Adoptive parent age at child birth was included as a covariate because prior research suggests that parental age influences children's physical activity (Bolen, Thomas, Heatherly, & Meredith, 2012). Openness of adoption was included to control for similarity between birth mother and adoptive parents that may be the result of contact and knowledge between the two sets of parents. Birth parents and adoptive parents reported on the level of openness in the adoption on a 7-point scale from (1) very closed (no information about the other set of parents) to (7) very open (communicates several times per month and visits at least once per month) (Leve et al., 2013). Sex of the child was included because, in general, male children tend to be more active than female children (Sallis et al., 2000). Finally, BM obstetric complications were included to control for prenatal or pregnancy and delivery related issues that might influence a child's physical activity. Obstetric complication scores were calculated using medical records based on the McNeil-Sjöström Scale for obstetric complications (Marceau et al., 2016; McNeil, Cantor-Graae, & Sjöström, 1994; McNeil, 1995) that includes pregnancy, labor and delivery, and neonatal complications.

Statistical Plan

First, we computed bivariate correlations between our potential covariates (i.e. age of AP at child birth, openness of adoption, sex of the child, and BM obstetric complications) and our study variables. Potential covariates that were significantly related to our study variables were controlled for by regressing them out of the construct and using the standardized residuals in subsequent analyses. Hierarchical linear regression analyses were then conducted using SPSS 23 to investigate the association between inherited and rearing environment influences on AC physical activity, and to examine whether rearing environment influences moderated the effect of inherited influences on AC physical activity. We examined 8 distinct models. Models 1 through 4 fit models examining BM BMI as an inherited influence and AP1 modeling, AP2 modeling, AP1 logistical support, and AP2 logistical support, respectively, as rearing environment influences. Models 5 through 8 fit models examining BM physical activity as an inherited influence and AP1 modeling, AP2 modeling, AP1 logistical support, and AP2 logistical support, respectively, as rearing environment influences. For each model, variables of interest were entered into the model, followed by the interaction term. When interactions were significant, simple slopes analyses were conducted to determine the direction of moderation effects.

Results

Preliminary Results

We examined AP age at child birth, openness of adoption, sex of the child, and BM obstetric complications as potential covariates. AP2 age, sex of the child, and BM obstetric complications were significantly associated with AC physical activity, AP2 modeling, and AP1 modeling, respectively, and therefore, were regressed out of the constructs prior to completing final analyses. Openness of adoption and AP1 age were not significantly associated with any of our study variables. The sample sizes, means, standard deviations, and ranges of our study variables are presented in Table 2.

Bivariate correlations revealed that BM BMI is not significantly associated with AC physical activity; however, BM physical activity is significantly associated with AC physical activity. AP1 logistical support is also significantly associated with AC physical activity, while AP2 logistical support, AP1 modeling, and AP2 modeling are not significantly associated with AC physical activity. Further information on the bivariate correlations for our primary study variables is presented in Table 3.

BM BMI & AP Modeling

Model 1 examined the inherited and rearing environment main effects of BM BMI and AP1 modeling on AC physical activity and the moderating effect of AP1 modeling on the relationship between BM BMI and AC physical activity. The overall model was not significant (F(3, 228) = 0.50, R^2 = .01, p = .68; see Table 4). There was no significant main effect of BM BMI (β = -.05, p = .44) or AP1 modeling (β = .08, p = .22) on AC physical activity. There was also no significant interaction between BM BMI and AP1 modeling (β = .00, p = .996).

Model 2 examined the main effects of BM BMI and AP2 modeling on AC physical activity and the moderating effect of AP2 modeling on the association between BM BMI and AC physical activity. The overall model was also found to be nonsignificant (F(3, 183) = 1.32, R^2 = .02, p = .27; see Table 4). There were no significant main effects of BM BMI (β = -.06, p = .44) or AP2 modeling (β = -.01, p = .90) on AC physical activity. However, there was a significant interaction between BM BMI and AP2 modeling (β = -.15, p = .049), indicating that the effect of BM BMI on AC physical activity depends on the level of AP2 modeling. Due to the nonsignificant overall model, however, the interaction was not investigated further.

BM BMI & AP Logistical Support

Model 3 examined the inherited and rearing environment main effects of BM BMI and AP1 logistical support on AC physical activity and the moderating effect of AP1 logistical support on the relationship between BM BMI and AC physical activity. The overall model was found to be nonsignificant (F(3, 228) = 2.47, R^2 = .03, p = .063; see Table 4). AP1 logistical support was positively associated with AC physical activity (β = .15, p = .026), indicating that when AP1 offered more logistical support, their children tended to be more physically active. BM BMI was not significantly associated with AC physical activity (β = -.04, p = .53). The interaction effect was also nonsignificant (β = -.11, p = .11).

Model 4 examined the main effects of BM BMI and AP2 logistical support on AC physical activity and the moderating effect of AP2 logistical support on the association between BM BMI and AC physical activity. The overall model was found to be nonsignificant ($F(3, 183) = 1.54$, $R^2 = .03$, $p = .21$; see Table 4). There was also no significant association between BM BMI ($\beta = -.03$, $p = .74$) or AP2 logistical support ($\beta = .05$, $p = .51$) and AC physical activity. The interaction between BM BMI and AP2 logistical support was significant ($\beta = -.15$, $p = .047$), indicating that the effect of BM BMI on AC physical activity depends on the level of AP2 logistical support. However, due to the nonsignificant overall model, the interaction was not investigated further.

BM Physical Activity & AP Modeling

Model 5 examined the inherited and rearing environment main effects of BM physical activity and AP1 modeling on AC physical activity and the moderating effect of AP1 modeling on the relationship between BM physical activity and AC physical activity. The overall model was found to be nonsignificant ($F(3, 195) = 2.25$, $R^2 = .03$, $p = .084$; see Table 5). BM physical activity was significantly associated with AC physical activity ($\beta = .17$, $p = .022$). There was no significant relationship between AP1 modeling and AC physical activity ($\beta = .08$, $p = .27$). There was also no significant interaction between BM physical activity and AP1 modeling ($\beta = .01$, $p = .92$).

Model 6 examined the main effects of BM physical activity and AP2 modeling on AC physical activity and the moderating effect of AP2 modeling on the association between BM physical activity and AC physical activity. The overall model was found to be nonsignificant

($F(3, 160) = 2.13$, $R^2 = .04$, $p = .099$; see Table 5). BM physical activity was significantly associated with AC physical activity ($\beta = .19$, $p = .019$). There was no significant relationship between AP2 modeling and AC physical activity ($\beta = -.01$, $p = .90$). There was also no significant interaction between BM physical activity and AP2 modeling ($\beta = .11$, $p = .18$).

BM Physical Activity & AP Logistical Support

Model 7 examined the inherited and rearing environment main effects of BM physical activity and AP1 logistical support on AC physical activity and the moderating effect of AP1 logistical support on the relationship between BM physical activity and AC physical activity. The overall model was found to be significant ($F(3, 195) = 3.37$, $R^2 = .05$, $p = .02$; see Table 5). BM physical activity was significantly associated with AC physical activity ($\beta = .15$, $p = .036$), suggesting that children of physically active birth mothers were more likely to be physically active. There was no significant main effect of AP1 logistical support on AC physical activity ($\beta = .13$, $p = .076$) and there was no significant interaction between BM physical activity and AP1 logistical support ($\beta = .11$, $p = .14$).

Model 8 examined the main effects of BM physical activity and AP2 logistical support on AC physical activity and the moderating effect of AP2 logistical support on the association between BM physical activity and AC physical activity. The overall model was significant ($F(3, 160) = 4.15$, $R^2 = .07$, $p = .007$; see Table 5) and BM physical activity was significantly associated with AC physical activity ($\beta = .19$, $p = .017$). AP2 logistical support was not significantly associated with AC physical activity ($\beta = .03$, $p = .70$). There was a significant interaction between BM physical activity and AP2 logistical support ($\beta = .21$, $p = .007$), suggesting that the effect of BM physical activity on AC physical activity depends on the level of AP2 logistical support.

A simple slopes analysis was conducted to clarify the direction of the interaction between BM physical activity and AP2 logistical support. In step 1 of the simple slopes analysis, a low AP2 logistical support variable was constructed. Subsequently, an interaction term was created between this new low AP2 logistical support variable and BM physical activity. The analysis revealed that the slope of BM physical activity and AC physical activity was not significant for low AP2 logistical support, $\beta = -.08$, $p = .465$ (see Figure 2). This finding suggests that when parents offered low levels of logistical support, there was not a significant difference in physical activity between children whose BMs reported low vs. high physical activity. In step 2 of the simple slopes analysis, a high AP2 logistical support variable was constructed. Subsequently, an interaction term was created between high AP2 logistical support variable and BM physical activity. The analysis revealed that the slope of BM physical activity and AC physical activity was significant for high AP2 logistical support, $\beta = .36$, $p = .003$. This finding suggests that when AP2 logistical support was high, there was a significant difference in physical activity between children whose BMs reported low versus high physical activity. Adopted children whose BMs reported high physical activity engaged in significantly more physical activity than children whose BMs reported low physical activity.

Discussion

To our knowledge, this was the first genetically-informed study to examine the influence of BM BMI, BM physical activity, and AP role modeling/logistical support on AC physical activity in middle childhood. Understanding how these heritable and environmental factors influence physical activity in childhood is crucial for targeting physical activity promotion for young children and their parents in hopes of combating obesity at an early age. The main objectives of our study were to: 1) disentangle select inherited (i.e. BM BMI and BM physical activity) and environmental (i.e. AP role modeling/logistical support) influences, 2) examine the unique effect of these inherited and environmental influences on AC physical activity, 3) examine inherited and environmental interaction effects on AC physical activity. Utilizing a genetically-informed adoption design enabled us to disentangle inherited and environmental influences and examine how these influences interact to impact AC physical activity.

A few key findings emerged from our study. First, BM BMI was not significantly associated with AC physical activity, while BM physical activity was significantly associated with AC physical activity. Neither AP1 nor AP2 role modeling was significantly associated with AC physical activity. AP1 logistical support, but not AP2 logistical support, was significantly associated with AC physical activity. We also found that AP2 logistical support moderated the relationship between BM physical activity and AC physical activity such that when AP2 logistical support was high, adopted children of high physical activity birth mothers engaged in high levels of physical activity, and adopted children of low physical activity birth mothers engaged in low levels of physical activity.

The nonsignificant association between BM BMI and AC physical activity was surprising in light of previously established evidence that BMI is highly heritable in middle childhood and influences physical activity (Wardle et al., 2008; Haworth et al., 2008; Remmers et al., 2014). This inconsistency could be due to the fact that BMI scores are calculated using only height and weight data, and fail to take into account muscle mass, bone density, and body composition (Centers for Disease Control and Prevention, 2011). Therefore, BMI may not be an entirely accurate or valid measure of physical fitness/health. However, the significant association between BM physical activity and AC physical activity is consistent with previous research that found mechanically-assessed physical activity (measured as activity level) to be genetically influenced (Saudino & Zapfe, 2008; Wood et al., 2007). This finding therefore provides support for some heritable influences on physical activity.

Regarding environmental influences on AC physical activity, there are a few plausible explanations for the nonsignificant association between AP1/AP2 modeling and AC physical activity. Because 9-year-old children are regularly attending school, interactions with parents and opportunities for parental role modeling may be less frequent. It is also possible that peers, and exercise role models outside the home (e.g. coaches, gym teachers, etc.), are beginning to play a more significant role in shaping children's physical activity and beliefs about the importance of physical activity. Additionally, because the present study utilizes self-report data from the parents, it's possible that parents reported more favorable behavior (i.e. more role modeling) than they actually perform or than children perceived them to have performed. For example, adoptive parents might report that they enjoy physical activity and exercise regularly, but might also elect to drive to work rather than walk/bike. Children may observe these behaviors, determine that convenience is more important than healthy living, and conclude that their parents don't place a high value on physical activity and positive health behaviors. It's also possible that positive (e.g. going for an evening jog) and negative (e.g. consistently taking the elevator instead of the stairs) role modeling may have a differential impact on child physical activity (Welk et al., 2003). A study by Fogelholm et al. (1999) examined this research question and found that the association between parent-child inactivity was stronger than the association between parent-child vigorous activity, suggesting that negative role modeling might have a more profound effect. A final potential explanation for these nonsignificant main effects is that the interaction between heritable characteristics and these environmental influences, as opposed to main effects alone, exhibits a greater influence on AC physical activity. Therefore, gene-environment interactions may be more important to understanding AC physical activity.

The finding that AP1 logistical support was significantly related to AC physical activity agrees with numerous studies that found parental logistical support to be positively related to child physical activity (Gustafson & Rhodes, 2006; Heitzler et al., 2006). Interestingly, in contrast to this literature, AP2 logistical support did not have a significant effect on AC physical activity. There are a few possible explanations for this finding. While we did not assess adoptive mothers and fathers specifically, AP1 is often the adoptive mother and AP2 is often the adoptive father. Therefore, when considering this, our findings regarding logistical support mirror previous findings on the effectiveness of maternal logistic support compared to paternal logistic support (Davison et al., 2003). It is also possible that because AP1 is often the primary caregiver (i.e. parent that spends the most time with the child), AP1 may be available to provide logistical support more frequently and consistently. Consequently, AP1 logistical support may have more of an impact than AP2 logistical support. It is also possible that there is a logistical support "threshold" (e.g. can only enroll in so many sports, can only be transported to so many activities, etc.) and once that threshold is reached, often by AP1, any excess logistical support does not add substantial value.

One of the primary goals of this study was to examine how heritable characteristics and rearing environment interact to influence child physical activity. Related to this objective, we found that there was a significant interaction between BM physical activity and AP2 logistical support. More specifically, when AP2 provided little support, there was no relationship between BM physical activity and AC physical activity. However, when AP2 provided a substantial amount of support, children of high physical activity BM engaged in high levels of physical activity and children of low physical activity BM engaged in low levels of physical activity. These findings don't support our initial hypothesis and suggest that increased AP2 logistical support creates an environment in which the child's inherited tendency to be more or less active is expressed. Instead of buffering against inherited risk, increased AP2 logistical support benefitted children who were already genetically inclined to be active by allowing them to reach their inherited potential and failed to benefit genetically at-risk children. One explanation for this finding is that high levels of logistical support may encourage children who enjoy activity or exhibit more innate athletic talent to continue to be active and engage in more physical activity. However, among those children who enjoy activity less or are less innately athletic, more logistical support (i.e. enrolling children in more sports that they don't want to be a part of, driving children to physical activity programs that they don't enjoy, etc.) may be met with resistance from the child and may invoke feelings of anxiety or inadequacy, potentially resulting in children spending more time on the bench or performing as little physical activity as possible during their activity. If children perceive that they are being forced into sports or physical activity programs, it may minimize their interest in any type of physical activity, organized or otherwise, and result in the expression of their inherited tendency to be less active. Another possible explanation for this finding is that a highly active child elicits more logistical support so that both parents are required to provide support in order to maintain the child's level of physical activity. A less active child requires less logistical support and might not reap the same benefits from being offered high levels of support from one or both parents.

Several limitations must be acknowledged when considering these findings. Many of our assessments were based on parent self-report data which generates issues of accuracy and bias (i.e. recall bias and social desirability bias). Additionally, our study used BMI as an indicator of physical fitness. As previously mentioned, BMI scores are based solely on height and weight and may not be the most accurate measure of body fat or overall physical health/fitness. Finally, because of limited birth father data, we elected not to include birth father BMI or physical activity in our study. This limitation prevented us from completely disentangling inherited and environmental influences and allowed us to only examine partial inherited influence contributed by the birth mother, instead of total inherited influence contributed by both parents.

Despite these limitations, these findings have significant implications for improving physical activity in middle childhood. Our study supports heritable influences on child physical activity, suggesting that some children are at greater heritable risk for being less active. Parents should be aware of this risk and create home environments that promote physical activity and healthy habits. Because logistical support from at least one parent also seems to be an effective tool to increase physical activity, parents should prioritize providing logistical support to their child(ren) especially during middle childhood when there are increased opportunities for structured physical activity (i.e. team and individual sports). The likelihood of parents providing support for their children and creating health-conscious home environments is inextricably linked to their beliefs about the importance of engaging in physical activity and other healthy behaviors (Vander Ploeg et al., 2012; Heitzler et al., 2006). When parents place a high level of importance on physical activity and healthy living, they will likely share these values with their children, offer more physical activity opportunities, and create a home environment that fosters development of positive health habits. Therefore, interventions created to promote physical activity should focus on educating both children and parents about the positive benefits that stem from physical activity and a healthy lifestyle.

Conclusion

The current study contributes to the child physical activity literature through providing support for inherited (i.e. BM physical activity) and environmental (i.e. AP1 logistical support) influences on AC physical activity, as well as interplay (i.e. AP2 logistical support moderates the relationship between BM physical activity and AC physical activity) between these influences in middle childhood. Through examining both adoptive parents, we were also able to investigate how AP1 and AP2 logistical support differentially affected AC physical activity (possibly because of parent gender or overall time spent with child). Our study highlights the need for additional research to better understand how heritable characteristics and the environment may interact to protect against inherited risk. Future research should clarify inherited and environmental influences on physical fitness by utilizing indicators of physical health/fitness other than BMI (e.g. waist circumference measurement, waist-to-hip ratio), examine children's perceptions of parental support, and investigate the differential impact of primary (i.e. parent that spends the most time with the child) vs. secondary caregiver support. Efforts should also be made to extend this work by investigating how the prenatal environment influences child physical activity and obesity risk, and how child physical activity influences child psychological problems (e.g. depression and anxiety).

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Tables

Table 1.

Demographic Characteristics of Birth Mothers, Adoptive Parents, & Adopted Child

(N = 361; Cohort I).

Variable	BM	AP1	AP2	AC
Age at child birth				
Mean	24.12 (5.89)	37.78 (5.50)	38.38 (5.78)	
Range	14.63 - 43.39	24.78 - 54.05	25.50 - 59.48	
Race/ethnicity				
Caucasian	71.1%	91.4%	90.2%	57.6%
African American	11.4%	3.6%	5%	11.1%
Hispanic/Latino	6.7%	2.5%	1.7%	9.4%
Multi-racial	5%	1.1%	1.1%	20.8%
Other	5.8%	1.5%	2%	1.1%
Education Level				
High school diploma or less	78.2%	12.8%	20.5%	
Some college	11.7%	10.3%	7.2%	
Bachelor's degree or higher	10.1%	76.8%	72.3%	
Household Income				
Mean	$20,600.44	$101,750.93	$105,250.79	
Employment Status				
Full Time	38.9%	32%	74%	
Part Time	14.4%	18.4%	2.9%	
Other	46.6%	49.6%	23.3%	

Note. BM = Birth Mother, AP1 = Adoptive Parent 1, AP2 = Adoptive Parent 2, AC = Adopted Child.

Table 2.

Descriptive Statistics for Study Variables.

Variable	***N***	**Range**	***M***	***SD***
Inherited Risk				
BM BMI	333	15.02-54.08	27.25	6.22
BM physical activity	284	17-57	37.67	7.60
Rearing Environment				
AP1 logistical support	244	2-4	3.52	.58
AP2 logistical support	192	1-4	3.31	.68
AP1 modeling	244	1-4	3.11	.61
AP2 modeling	192	1-4	3.14	.59
Child Physical Activity	234	.03-.69%	29.81%	11.64%

Note. BM = Birth Mother, AP1 = Adoptive Parent 1, AP2 = Adoptive Parent 2, BMI = Body Mass Index. Child Physical Activity range, mean, and standard deviation refer to the percent of time spent in activity overall.

Table 3.

Bivariate Correlation Coefficients of the Study Variables.

	1.	2.	3.	4.	5.	6.	7.
1. BM BMI	-						
2. BM physical activity	.34**	-					
3. AP1 logistical support	-.04	.21**	-				
4. AP2 logistical support	-.02	-.04	.39**	-			
5. AP1 modeling	.03	.02	.30**	.11	-		
6. AP2 modeling	-.05	.06	.16*	.41**	.25**	-	
7. AC physical activity	-.06	.17*	.13*	.05	.07	.02	-

Note. BM = Birth Mother, AP1 = Adoptive Parent 1, AP2 = Adoptive Parent 2, AC = Adopted Child, BMI = Body Mass Index.
*p < .05, **p < .01.

Table 4.

BM BMI Multiple Regression Analyses.

Variable	BM BMI + AP1 log	BM BMI + AP2 log	BM BMI + AP1 Modeling	BM BMI + AP2 Modeling
BM BMI	-.04	-.03	-.05	-.06
AP 1 Logistical Support	.15*			
AP2 Logistical Support		.05		
AP1 Modeling			.08	
AP2 Modeling				-.01
BM BMI * AP1 Logistical Support	-.11			
BM BMI * AP2 Logistical Support		-.15*		
BM BMI * AP1 Modeling			.00	
BM BMI * AP2 Modeling				-.15*
F Value	$F(3, 228) = 2.47$	$F(3, 183) = 1.54$	$F(3, 228) = .50$	$F(3, 183) = 1.32$
R Square	.03	.03	.01	.02

Note. BM = Birth Mother, AP1 = Adoptive Parent 1, AP2 = Adoptive Parent 2, BMI = Body Mass Index.
*$p < .05$, **$p < .01$.

Table 5.

BM Physical Activity Multiple Regression Analyses.

Variable	BM PA + AP1 Log Support	BM PA + AP2 Log Support	BM PA + AP1 Modeling	BM PA + AP2 Modeling
BM PA	.15*	.19*	.17*	.19*
AP1 Logistical Support	.13			
AP2 Logistical Support		.03		
AP1 Modeling			.08	
AP2 Modeling				-.01
BM PA * AP1 Logistical Support	.11			
BM PA * AP2 Logistical Support		.21**		
BM PA * AP1 Modeling			.01	
BM PA * AP2 Modeling				.11
F Value	$F(3, 195) =$ 3.37*	$F(3, 160) =$ 4.15**	$F(3, 195) =$ 2.25	$F(3, 160) =$ 2.13
R Square	.05	.07	.03	.04

Note. BM = Birth Mother, AP1 = Adoptive Parent 1, AP2 = Adoptive Parent 2, AC = Adopted Child, BMI = Body Mass Index.
$*p < .05$, $**p < .01$.

Figures

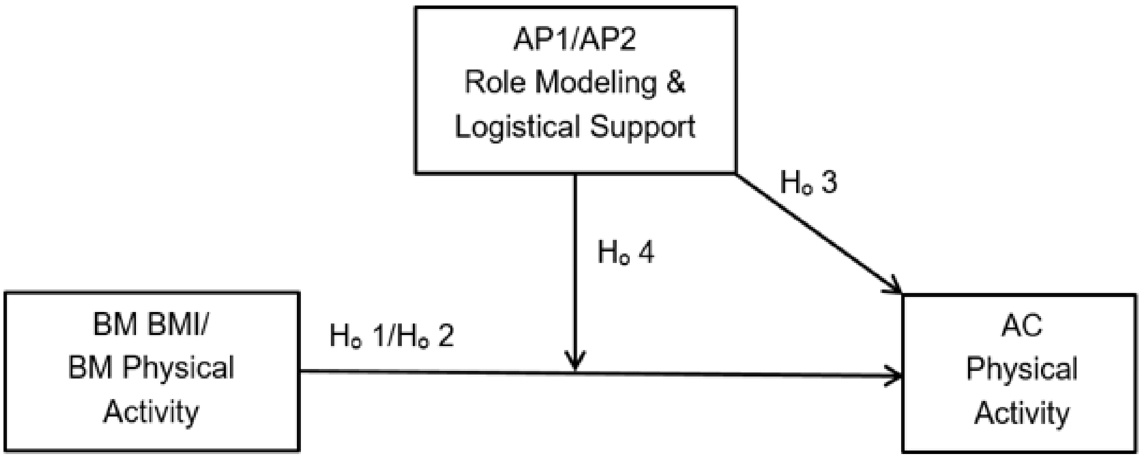

Figure 1. Conceptual model. Inherited (i.e. BM BMI & BM physical activity) and Environmental (i.e. AP1/AP2 role modeling & logistical support) influences on AC physical activity.

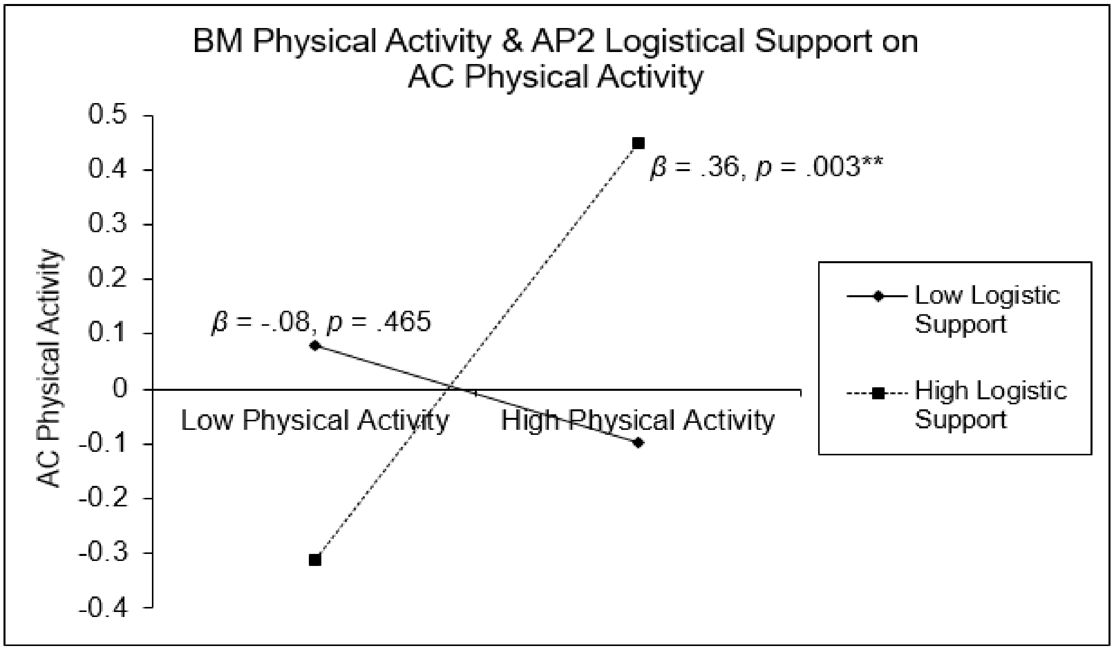

Figure 2. The moderating effects of AP2 logistical support on the relationship between BM physical activity and AC physical activity.

*p < .05, **p < .01.

Academic Vita

Grace D. Davis

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Education

Bachelor of Science in Psychology, Business Option Graduation: August 2017
Minor: Statistics
Schreyer Honors College
The Pennsylvania State University, University Park, PA

Study Abroad January 2017 – May 2017
CEA Barcelona & University of Barcelona
- Completed course work in Nonprofit Management & Spanish Language/Culture
- Improved Spanish language ability from beginner to intermediate
- Volunteered with an arts-based English language immersion program for local children

Study Abroad July 5 – August 5, 2015
Schreyer India Program
- Participated in exchange programs & group projects with university students in India
- Completed coursework focused on India prior to departure and upon returning

Study Abroad May 30 – June 29, 2014
Global LEAD Greece Program
- Focused on service learning, leadership development, and cultural understanding

Research Experience

Research Assistant Fall 2014 – Spring 2016
Department of Psychology, Penn State University
Supervisors: Dr. Jenae Neiderhiser & Dr. Ginger Moore
- Early Growth and Development Study
- Reliably coded qualitative research videos in order to categorize behaviors for analysis
- Conducted extensive literature review on differential susceptibility
- Attended weekly lab meetings
- Presented thesis findings

Leadership & Work Experience

Undergraduate Teaching Assistant Fall 2016
Department of Psychology, Penn State University

Supervisor: Dr. Jeff Love

- Answered student questions and assisted students who were struggling with the material
- Provided lecture notes to absent students
- Prepared and led exam review sessions
- Compiled data from extra credit assignments for use by the professor in lectures
- Proctored exams

Exam Proctor Spring 2015 – Fall 2016

Department of Psychology, Penn State University

- Distributed and proctored exams
- Answered questions and reported suspicious behavior
- Collected exams upon completion

Habitat for Humanity Fundraising Chair Fall 2015 – Fall 2016

Penn State Campus Chapter

- Planned, organized, and supervised alternative fundraising events
- Led two Habitat for Humanity Alternative Spring Break Trips (Spring 2015 & 2016)
- Attended weekly executive board meetings and general member meetings
- Held weekly office hours

International Justice Mission Treasurer Spring & Fall 2016

Penn State Campus Chapter

- Managed cash flow from fundraising events
- Handled receipts, transactions, and reimbursements
- Assisted with the planning and coordination of chapter events

Ronald McDonald Family Room Intern June 2016 – August 2016

Penn State Hershey Medical Center

- Supervised volunteers
- Acted as a liaison between volunteers and management
- Organized special events

Intern June 2015 – July 2015

Habitat for Humanity of the Greater Harrisburg Area

- Managed volunteer information and created volunteer recruitment webpages at Habitat ReStore
- Headed a fundraising project and developed an annual report
- Initiated the creation of Habitat Campus Chapters at local universities

Posters

Davis, G. D., Ramos, A. M., Neiderhiser, J. M., Reiss, D., Shaw, D. S., Leve, L. D., Mitchell, D., & Ganiban, J. M. (2017, April). *What explains physical activity in children? An adoption* *study*. Poster presented at the biennial meeting of the Society for Research in Child Development, Austin, TX.

Honors & Scholarships

● Penn State College of the Liberal Arts Student Marshal	2017
● Dean's List	2012 – 2017
● Schreyer Honors College Academic Excellence Scholarship	2012 – 2016
● Phi Beta Kappa	2016
● Penn State Evan Pugh Scholar Award	2015 & 2016
● Penn State Psi Chi Honor Society	2015
● Penn State President's Freshman Award	2013