# TEMPORAL PATTERNS OF PHYSICAL ACTIVITY IN YOUTH

By

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A DISSERTATION

Submitted to:
Michigan State University
in partial fulfillment of the requirements
for the degree of

Kinesiology – Doctor of Philosophy

2023

## PUBLIC ABSTRACT

The importance of regular, habitual physical activity (PA) for youth is well supported by its many established health benefits. Even with these known benefits, past studies show that less than 25% of youth 6 to 17 years of age participate in 60 minutes of PA every day. Previous literature has also shown that PA behaviors developed as a child may track into adulthood. Taken together, these findings highlight the importance of examining youth PA and studying different and new strategies to promote PA to determine how, when, and where children are being active. By doing so, researchers may be able to effectively promote PA in youth moving forward, and more importantly, help children develop healthy lifestyle habits early so that they can take these habits with them into adulthood. In the current literature, there is a lack of information regarding the timing of PA and patterns that may exist (temporal patterns) in youth PA throughout the days/weeks/months/seasons—which if examined in more detail, could hold the key to developing new and improved promotional strategies, and identifying time periods where PA should be promoted most. Therefore, the purpose of this dissertation was twofold. First, to identify and summarize the existing literature on temporal patterns of PA in youth, and second, to make suggestions for future research to identify optimal times to improve PA promotion strategies and eventually, the overall health of our youth. This dissertation is comprised of three separate manuscripts. Manuscript 1 is a systematic literature review of all aspects of temporal patterns of youth PA. After reviewing the 30 studies included in the literature review, results showed that studies examining the temporal patterns of PA in youth have largely varying results (age, sex, setting etc.), with evidence for two different patterns called PA compensation, and PA synergy. Manuscript 2 is a study which examined the PA of racially diverse, low socioeconomic statues (SES) adolescent girls at different times of the day (before school, during school, after

school, and evening). This study found evidence for both compensation and synergy in an examination of school day PA in adolescent girls. PA levels, in general, rose and fell throughout the school day for all girls, showing evidence for compensation. Girls who were highly active relative to their peers stayed highly active throughout the day and those who were inactive stayed inactive, exhibiting evidence for synergy. Manuscript 3 is a study which examined PA in adolescent girls from the same sample during an afterschool PA club, focusing on participant characteristics that may be predictive of PA during this important time of the day and a comparison of afterschool PA to normal after school PA behavior. Results from this study show that, in general, PA during the afterschool club was higher than normal after school PA, but no participant characteristics were predictive of an increase in PA behavior from normal after school time to PA during the afterschool club. It was also observed that girls in later stages of maturation accumulated less PA during the afterschool PA club. This dissertation underscores the need for a better understanding of temporal patterns of physical activity in youth. It gives insight into how the school day structure has a strong influence on the activity level of youth and highlights the need for appropriate promotional strategies and innovative school-based interventions to increase overall PA levels. More research is needed to help researchers create effective programs to help youth become more active, with the end goal being to help children become healthy, active adults.

## ABSTRACT

The health benefits of habitual physical activity (PA) in youth are well-established through several sources of research. Despite the known benefits, surveillance studies at the population level suggest that less than one-quarter (24%) of youth 6 to 17 years of age participate in 60 minutes of physical activity every day. Additionally, previous literature has shown that PA behaviors developed as a child may track into adulthood. Taken together, these facts highlight the importance of examining children's (6–11 yrs.) and adolescents' (12–17 yrs.) PA and studying different PA promotion strategies in greater depth to determine how, when and where children are being active or are more likely to be active. By doing so, researchers may be able to effectively promote PA in youth moving forward, and help children develop healthy lifestyle habits early so that they can take these habits with them into adulthood. The majority of the existing literature on PA focuses on time spent in specific PA intensity levels (light, moderate, or vigorous), or simply on total daily PA, with very little research examining the temporal patterns of PA. Evaluating temporal patterns of PA supports the notion that all people, youth included, may follow distinct patterns in their PA within a day and/or over the course of the days, weeks, months, and seasons. Therefore, the purpose of this dissertation is twofold. First, to identify and summarize the existing literature on temporal patterns of PA in youth, and second, to make suggestions for future research to identify optimal times to improve PA promotion strategies and eventually, the overall health of our youth. This dissertation is comprised of three separate manuscripts. Manuscript 1 is a systematic literature review to examine and summarize all aspects of temporal patterns in youth PA. Patterns examined in this review included within-day PA (n=13; 43.3%), day-to-day PA (n=7; 22.5%), longitudinal PA (n=2; 6.7%), weekday PA only (n=2;6.7%), weekday vs. weekend PA (n=15; 30%), PA Compensation (n=12; 40%), and PA

Synergy (n=3; 10%). Findings suggest that studies examining the temporal patterns of PA in youth have largely varying results (age, sex, setting etc.). Manuscript 2 is a study which aimed to identify temporal patterns during the school day and participant characteristics that may be associated with higher levels of PA in a PA intervention in girls from urban, low SES areas with a high percentage of racial/ethnic minorities during a PA intervention. Kendall's tau revealed significant correlations ($p<0.001$) for average MVPA min/hr between all four time periods, with the strongest correlation occurring between after-school and evening time periods ($f=0.563$, $p<0.001$), Results showed that girls' PA levels, in general, rose and fell throughout the day, while girls who were more active relative to their peers remained more active and those who were relatively inactive stayed inactive. Manuscript 3 is a study which examined PA during an after-school program to identify patterns and predictive participant characteristics of PA behavior. Results showed that every minute increase in average afterschool moderate-to-vigorous PA (MVPA) min/hr at baseline was associated with a corresponding additional 3.90 minutes of MVPA min/hr during the PA club ($ß=3.90 \pm 0.31$, $p<0.001$). No participant characteristics were found to be predictive of PA behavior. This dissertation underscores the need for a better understanding of temporal patterns, provides insight into how the school day structure is a driving force in the activity level of youth, and highlights the need for appropriate promotional strategies and innovative school-based interventions to increase overall PA levels, with the end goal being to help children become healthy, active adults.

## ACKNOWLEDGMENTS

I would first and foremost like to acknowledge and thank Dr. Karin Pfeiffer for all her work, support, and patience as she guided me through this dissertation process. I've already seen the benefits of her guidance and teaching manifest in my professional career and will continue to utilize her expertise and mentorship. I would also like to thank the following collaborators and colleagues – my graduate and undergraduate research helpers, Danielle Vering and Cailyn VanCamp for their help with data collection, and Dr. Dhruv Sharma and Dr. Kimberley Clevenger for their help and guidance with statistical analysis. I would also like to extend a big thank you to the other members of my dissertation committee – Dr. Lorraine Robbins, Dr. Mat Reeves, and Dr. Spyridoula Vazou, all of whom contributed hard work and quality feedback that have made my dissertation better. I appreciate their time and support as I navigated this process.

Next, I would like to thank my family members for their endless love and support. Specifically, I would like to thank my wife, Jamie, for sticking with me through the good and the bad times, the anxiety, tears, and late nights, as well as all the good times we had together in East Lansing and at Michigan State. I truly mean it when I say that I could not have done this without her. I would like to thank my parents Mike and Jayne for their constant emotional and financial support through all my years of higher education. Their patience, encouragement, and generosity made this possible for me. I would like to thank my grandfather, Dr. Jim Timmer, who also has his Ph.D. in Exercise Science. His love, encouragement, expertise, and constant reminders to "get it done!" inspired me to complete this dissertation. I did it, Grandpa! Finally, I would like to thank the MSU Department of Kinesiology and College of Education for providing funding for these projects and Michigan State University for the opportunity to study at such a prestigious school. GO GREEN!

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| PA | Physical Activity |
| MVPA | Moderate-to-Vigorous Physical Activity |
| TPA | Total Physical Activity |
| GOTM | Girls on the Move Intervention |
| BMI | Body Mass Index |
| YRBSS | Youth Risk Behavior Surveillance System |
| SES | Socioeconomic Status |
| PAL | Physical Activity Level |
| MET's | Metabolic Equivalents |
| NHLBI | National Heart, Lung, and Blood Institute |
| WD | Within-day |
| DD | Day-to-day |
| L | Longitudinal |
| WKD | Weekday only |
| WVW | Weekend vs. Weekday |
| COMP | Compensation |
| SYN | Synergy |

# Chapter 1: Dissertation Introduction

## Temporal Patterns of Physical Activity in Youth

Michael J. Wierenga

## INTRODUCTION

The health benefits of habitual physical activity (PA) in youth are well-established through several sources of research.[1] Despite the known benefits, surveillance studies at the population level suggest that less than one-quarter (24%) of youth 6 to 17 years of age participate in 60 minutes of physical activity every day.[2] Additionally, previous literature has shown that PA behaviors developed as a child may track into adulthood.[3] Taken together, these facts highlight the importance of examining children's (6–11 yrs.) and adolescents' (12–17 yrs.) PA and studying different PA promotion strategies in greater depth to determine how, when and where children are being active. By doing so, researchers may be able to effectively promote PA in youth moving forward, and more importantly, help children develop healthy lifestyle habits early so that they can take these habits with them into adulthood.

### *Importance of PA in Girls*

PA behavior in girls is especially important as literature shows a drastic decrease in PA as girls age. Telford et al., 2016 found girls to be 19% less active than boys. Furthermore, girls compared to boys had less favorable individual attributes associated with PA at age 8 years, including 18% lower cardio-respiratory fitness, 44% lower eye-hand coordination 5% higher percent body fat, and 9% lower perceived competence in physical education.[33]

According to the CDC's Youth Risk Behavior Surveillance, only 22% of girls meet the national recommendations of at least 60 minutes of PA every day by the time they reach 9$^{th}$ grade.[18,20,21] To make matters worse, by this same age, 28% are already overweight or obese.[18,20,21] This decline in PA as girls aged coupled with associated increase in body mass index (BMI) and adiposity makes the promotion of healthy PA behaviors in this group of utmost concern.[22,23,24,25,26] Therefore, there is a strong need for new PA promotion strategies to be

established in order to combat and eventually reverse risk adverse health outcomes especially amongst youth girls.[27,28]

***Racial and Ethnic Minorities***

Previous literature has noted that PA behavior amongst youth in differing racial and ethnic minority groups is highly variable.[29] Black and Hispanic youth report less PA on average that their white peers and are also more likely to report no physical activity.[29,30] In a study by Keaton et al. (2008) examining data from the 2007 national Youth Risk Behavior Surveillance System (YRBSS), the authors found that overall, the prevalence of not participating in 60 or more minutes of physical activity on any day was higher among Black (32.0%) and Hispanic (27.1%) than white (22.4%) youth.[31] According to a study by Drenowatz et al. (2010), children from lower socioeconomic status (SES), low income areas that are primarily Black and Hispanic show a trend of having lower PA levels and more time spent in sedentary time than those in higher SES areas.[31] This study revealed that mean daily steps differed significantly among SES groups with lower SES groups approximating 10,500 steps/day compared to about 12,000 steps/day in the higher SES groups. [31] Furthermore, declining PA is particularly evident among urban, minority girls of low socioeconomic status (SES). [17,34,35,36] It is, therefore, important to examine PA in racial and ethnic minority groups in low SES areas, especially girls, to see how they may differ from white peers and high SES areas. Information regarding patterns in these groups and areas may be useful in improving PA promotions for these underserved youth.

***Temporal Patterns of PA***

The majority of the existing literature on PA focuses on time spent in specific PA intensity levels (light, moderate, or vigorous), or simply on total daily PA. Intensity and quantity, however, may only be a small piece of the larger pie that is youth PA. One factor that may have a

large impact on children's overall PA behavior but has not been examined thoroughly in the existing literature, is the temporal patterns of PA. Evaluating temporal patterns of PA supports the notion that all people, youth included, may follow distinct patterns in their PA within a day and/or over the course of the days, weeks, months, and seasons. An in-depth examination of temporal patterns of PA in youth may lead to identification of specific times where effective PA promotion could be implemented to help children become more active and healthier overall.

The existing, limited literature regarding temporal patterns of PA suggests that there is variation across time periods including, within-day patterns, day-to-day patterns, weekly patterns, seasonal patterns, and even patterns across a person's lifespan. These patterns could also be observed in various PA settings in which children participate daily, such as school, PE class, recess, sports games/practices, and afterschool programs/free play. Thus, the notion of temporal patterns could encompass a wide variety of circumstances.

***Identifiable Patterns in the Existing Literature***

There are two opposing theories of temporal patterns of PA that have been identified in the existing literature. The first, PA compensation (also known as the activitystat hypothesis), suggests that children compensate for increased PA during one time-period by decreasing their PA in another time-period (or vice versa) in order to maintain an innate total amount of PA (Figure 1.1). In opposition to PA compensation is the hypothesis of PA synergy. This hypothesis suggests that youth do not compensate, but rather, build on times of high (or low) PA with additional periods of high (or low) PA (Figure 1.1).[4] The current literature lacks definitive evidence, however, to suggest which of these patterns actually occurs or if both occur depending on the surrounding environment and individual level characteristics. Future research must compile information regarding how these mechanisms of temporal patterns manifest as well as

which individual factors (e.g., age, sex, cardiovascular fitness, and body composition) are most important in order to determine how best to achieve optimal PA for children. Furthermore, synergy and compensation are not necessarily the only way to examine the PA patterns of youth, therefore, future studies should explore different ways to characterize the temporal patterns of youth.

| PA COMPENSATION | PA SYNERGY |
|---|---|
| Periods of ⬆ PA lead to periods of ⬇ PA | Periods of ⬆ PA lead to periods of ⬆ PA |
| Periods of ⬇ PA lead to periods of ⬆ PA | Periods of ⬇ PA lead to periods of ⬇ PA |

**Figure 1.1: Comparison of PA Compensation and PA Synergy**

***Within-Day, Day-Day, Seasonal, and Year-to-Year PA***

Temporal patterns can be observed over small periods of time or long periods of time. In the literature, these different time periods are referred to as "within-day" patterns, "day-to-day" patterns, "seasonal" patterns, and "year-to-year" patterns. With respect to within-day PA of youth Mota et al. (2003) showed that on average, boys had more moderate-to-vigorous physical activity (MVPA) over the course of the day than girls. The researchers also observed that girls are generally more active in the morning and early afternoon hours, while boys are more active in the late afternoon and evening.[10] In a similar study, DaBaere et al. found that PA levels (PAL) were generally highest during the early evening (2.51 $MET_{SWM}$ ) and school hours (2.49 $MET_{SWM}$ ), and that the late evening time period showed significantly less PA(2.21 $MET_{SWM}$ ) and the highest proportion of sedentary time for youth (54 % of total time-use).[11] These results from previous studies highlight the variability that may exist in youth PA throughout the day and between sexes.

Day-to-day patterns of youth PA have been examined in the previous literature by observing differences in PA across weekdays, between weekday vs weekend days, or in-school vs. out-of-school days, among others. In a study by Brooke et al., the authors found that PA bout frequency was higher on weekdays than weekends (median [IQR] 4.3 [2.2–7.2] vs. 3.0 [1.0–6.5] bouts/day, $p < 0.001$); however, PA bout duration did not differ (4.7 [4.0–5.7] vs. 4.5 [3.7–5.8] min/bout, $p = 0.33$). Additionally, more PA bouts were accumulated out-of-school compared to in-school (2.2 [1.0–4.0] vs. 1.8 [0.8–3.2] bouts/day, $p < 0.001$), but bout duration was similar (4.7 [3.8–5.8] vs. 4.5 [3.8–5.7] min/bout, $p = 0.158$). The authors concluded that characteristics of youth PA vary between days.[12]

Unlike some of the other PA patterns, seasonal variation in PA has been well documented.[13,14,19] A study by Atkin et al. from the United Kingdom showed that MVPA was lower in autumn and winter relative to spring, with the size of the difference varying by weekday/weekend, sex, weight status, urban/rural location, and family income ($p<0.05$ in all cases). Total sedentary time was also found to be greater in autumn and winter compared with spring, and the seasonal effect was seen to be stronger during the weekend than during the weekday ($p<0.01$).[13] Additionally, in a review by Carson & Spence, the authors noted that 83% of studies examined found seasonal variation in PA. These variations were found to be consistent regardless of the region, measure of PA, or the study design, but were inconsistent across ages.[14] In regard to PA compensation and synergy, it would seem that seasonal variation, especially in locations that experience all four seasons, creates environments that breed PA compensation, with lower PA during the autumn and winter and higher PA during spring and summer.

Research also suggests that youth follow certain patterns in their PA from year-to-year as they age. A study by Lau et al. in 2017 found that school-day total PA (TPA) and MVPA

declined as children aged and that the most significant decrease was from 5th to 6th grade. The authors also observed that after-school TPA declined significantly from 5$^{th}$ to 6$^{th}$ grade for both boys and girls, while MVPA increased for girls and stayed stable for boys during the same time-period. Finally, evening TPA decreased significantly for both, and MVPA declined significantly in girls and stayed stable in boys as they aged.[15] Another study examined longitudinal PA and sedentary trends in PA from youth and adulthood and concluded that the vast majority of adolescents do not achieve current PA guidelines and continue to fail to achieve them into adulthood, suggesting evidence for long-term PA synergy (Low PA → Low PA).[16] Longitudinal examination of PA patterns is especially important for youth as previous literature suggests that PA behavior exhibited as a child may track into adulthood.[3]

Although there is existing literature which examines compensation, synergy, within-day PA, day-to day PA, seasonal PA, and year to year PA, we still do not have research that connects all of these pieces in order to fully characterize the temporal patterns of PA in youth as well as which factors may influence them. Particularly important is the fact that information is missing from existing literature regarding temporal patterns of PA in underrepresented populations. In order to do this, researchers must continue to examine temporal patterns in different settings, populations, and across different time periods. More research regarding temporal patterns of PA and the factors that influence them may be useful for developing new PA interventions targeted at specific times during the day/week/months/and seasons. Furthermore, new information on the topic of temporal patterns of PA in youth may lead to better and more targeted promotion of PA during periods where it is lacking.

### *Girls on the Move Intervention*

Examination of temporal patterns in this dissertation will be performed using data from the Girls on the Move (GOTM) study. GOTM included a 17-week after-school intervention targeting middle school aged girls and aimed to increase overall PA behavior by incorporating the Health Promotion Model (HPM) and the Self-Determination Theory (SDT). The intervention itself was made up of three main components which included **1)** Two face-to-face motivational counseling sessions which were facilitated by the school nurse/other trained personnel and tailored to each individual (occurred at baseline and 17 weeks); **2)** an interactive, internet-based session where each participant received motivational and feedback messages, once again tailored to each individual (occurred at 9 weeks); and **3)** a group level component consisting of a 90-minute PA club which was led by PA instructors (e.g., individuals from community; teachers, including physical education (PE); and sports team coaches). More detailed information and explanation of the GOTM intervention study, its methods, and its results are listed in previous publications and later in this document.[17,18]

Results showed that girls who participated in the GOTM intervention maintained but did not increase levels of MVPA when compared to girls in the control group. However, specific time periods and patterns during the day/week, as well as if any participant characteristics may influence these patterns were not examined.[17,18] The overall purpose, aims, and hypotheses of this dissertation follow.

**Purpose:** The purposes of this dissertation are to summarize the existing literature concerning temporal patterns of PA in youth and to examine temporal patterns at different times and in different settings amongst middle school-aged girls in the GOTM intervention study.

**Manuscript 1: Systematic Review Purpose**

The purpose of this systematic review is twofold: 1) to identify and summarize the existing literature on temporal patterns of physical PA in youth, and 2) to make suggestions for future research in order to suggest optimal times to improve PA promotion strategies and eventually, the overall health of our youth.

**Manuscript 2: Specific Aims/Hypotheses**

**Aim 1.** To compare average MVPA min/hr across different time-points during the day, "before-school time", "during-school time", after-school time", and "evening", to search for possible associations and patterns in PA across these time periods in a group of adolescent girls, a high percentage of whom are Black, who come from a predominantly low-income background.

**Hypothesis 1a.** Average MVPA min/hr during "before-school time" will have a significant and positive association to average MVPA min/hr in "during-school time". (Evidence for Synergy)

**Hypothesis 1b.** Average MVPA min/hr occurring in "during-school time" will have a significant and negative association to average MVPA min/hr in "after-school time". (Evidence for Compensation...suppressed PA time during the school day leads to higher MVPA after school)

**Hypothesis 1c.** Average MVPA min/hr during "after-school time" will have a significant and negative association to average MVPA min/hr during "evening time". (Evidence for Compensation).

**Aim 2.** To examine participant factors associated with average MVPA min/hr at these different time points.

**Hypothesis 2:** Participants' cardiorespiratory fitness, percent body fat, race/ethnicity, and age will be significantly related to average MVPA min/hr achieved in these different time periods.

**Manuscript 3: Specific Aims/Hypotheses**

**Aim 1:** To examine the extent of the difference between average MVPA min/hr achieved during the GOTM after-school PA club and average MVPA min/hr achieved in the after-school time-period at baseline of the GOTM intervention.

**Hypothesis 1.** Average MVPA min/hr during the after-school PA club will be significantly higher than that achieved during the after-school period at baseline.

**Aim 2:** To identify differences in average MVPA min/hr during the after-school PA club between schools while controlling for baseline after-school MVPA min/hr

**Hypothesis 2:** There will be no differences between schools in average MVPA min/hr achieved during the after-school PA club.

**Aim 3:** To identify individual participant factors that may be associated with significant increases in MVPA min/hr during after-school time from baseline to the after-school PA club while controlling for school and overall, baseline MVPA.

**Hypothesis 3.** Body fat percentage (negative association), cardiorespiratory fitness (positive association), maturity status (negative association), age (negative association), and race/ethnicity will all be associated with a significant increase in average MVPA min/hr during the after-school club.

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**Chapter 2: Manuscript 1**

# A Systematic Review of the Temporal Patterns of Physical Activity in Youth

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**ABSTRACT**

The authors conducted a systematic review of studies that address changes in the timing of physical activity (PA) behavior in youth, also known as temporal patterns of physical activity. The purposes of this systematic review are: 1) identify and summarize the existing literature on temporal patterns of PA in youth; and 2) make suggestions for future research to identify the optimal PA promotion strategies. This systematic review was accomplished through a search of PubMed, Web of Science, and SPORTdiscus. Eligible studies were peer-reviewed articles included observational cohort, cross-sectional, or interventions study designs that specifically examined temporal patterns or timing of PA for youth aged 3–17 years (pre-school through adolescence). Of 50 potential studies identified, 30 articles met eligibility criteria ; patterns examined included within-day PA (n=13; 43.3%), day-to-day PA (n=7; 22.5%), longitudinal PA (n=2; 6.7%), weekday PA only (n=2;6.7%), weekday vs. weekend PA (n=15; 30%), PA Compensation (n=12; 40%), and PA Synergy (n=3; 10%). Results showed that studies examining the temporal patterns of PA in youth have largely varying results (age, sex, setting etc.), with evidence for both PA compensation and PA synergy. More research is needed in this area before researchers can test potentially? effective strategies for promoting PA in youth.

## INTRODUCTION

The importance of participation in regular, habitual physical activity (PA) and its contribution to significant health benefits is well documented. [17,31,48] Habitual PA is especially important for children and adolescents, as previous research has found that PA behaviors learned during the early years track into adulthood.[41] Although the importance and benefits of PA for youth have been well-documented, the 2022 United States Report Card on Physical Activity for children and youth reported that only 16% of US children and adolescents participated in the recommended 60 minutes of PA each day from 2016–2018. [27,28] These results highlight the need for researchers, health professionals, teachers, community leaders, and policy makers to continue to develop new and innovative ways to support a healthy environment for our youth and increase habitual PA during childhood and adolescence.

With this information in mind, it becomes imperative to find effective and innovative strategies to help youth be more physically active and encourage children and adolescents to meet the recommended guidelines of 60 minutes of PA per day. Most of the existing literature is focused on examining the amount of time spent in sedentary behavior or screen time or have measures PA based on specific PA intensities (light, moderate, moderate to vigorous (MVPA), or vigorous), or the total daily amount (minutes) of achieved of PA. Temporal patterns of PA in youth are rarely examined, and even less research with the purpose of understanding these patterns to improve existing PA promotion strategies exists. These PA patterns could be found at any time during the days, weeks, months, and even longitudinally for more than a year. The different patterns that exist and their etiology may differ, but the purpose of temporal patterns of PA research is to identify any existing patterns and determine how they can be used to increase PA behavior amongst youth. To fully understand how to best promote PA and increase the

amount of youth achieving the PA guidelines, we must have a thorough understanding of the temporal patterns that children often exhibit in their PA behavior.

Examining temporal patterns of PA involves focusing on the concept that individuals follow specific patterns in their PA behavior within a given day and/or over multiple days, months, weeks, and seasons. Existing literature on this topic is diverse, with studies examining various time periods such as within-day or hour-to-hour PA, day-to-day PA, and even longitudinal PA patterns across years. Studies have also examined various factors that may influence temporal patterns such as sex, weight and body composition, age, socioeconomic status, parents' PA, and seasonal influence. Regardless of the type of temporal pattern being addressed by a particular researcher, a deeper examination of temporal patterns presents a unique opportunity to learn when youth are most active, and how PA during one specific time may influence future PA behavior.

The most intriguing research for temporal patterns in PA, however, exists in the examination of two specific activity patterns. The first pattern, known as PA compensation, was first explained by the activitystat hypothesis, which suggests that children compensate for increased PA in one part of the day by decreasing their PA in another part of the day (or vice versa) to maintain an innate total amount of PA [34] An example of compensation would be if a child increases PA after school in response to low physical activity levels during school time. In contrast to the PA compensation is the PA synergy hypothesis. The theory of PA synergy posits that youth do not compensate for overall PA, but rather build on times of high/low PA with additional periods of high/low PA to be more synergistic with their PA totals.[6] An example of synergy would be if a child is highly active throughout the school day and continues this pattern

of high PA into the afterschool and evening periods. Research findings regarding these two hypotheses are largely conflicting, with studies showing support for both patterns.

More information concerning these specific patterns, as well as other time-points and factors influencing other temporal patterns in youth PA, may provide evidence to improve PA promotion and help us design types of activities that fit into existing habitual temporal patterns during different time periods of days, weeks, months, and seasons. The current research lacks a definitive framework for how to define and examine temporal patterns of youth physical activity. There is also little continuity in study design, duration, sample, and PA measurement technique (i.e., accelerometer, pedometer, heart rate monitor, direct observation, GPS tracking) amongst studies examining temporal patterns. More information must be gathered regarding temporal patterns in youth PA, so that a framework for defining patterns and their effects on overall PA and other individual characteristics can be developed. For example, if we know that youth are less active during school time and more active during the after-school period, we can tailor interventions to provide more opportunities for youth to be active during the school period and utilize the afterschool period to teach youth about healthy PA habits during a time when they are already active. To our knowledge, no existing research has been conducted which uses information about youth PA patterns to structure an intervention. Additionally, no other systematic reviews exist which examine all temporal patterns of physical activity in youth.

The purpose of this systematic review is twofold: 1) to identify and summarize the existing literature on temporal patterns of physical PA in youth, and 2) to make suggestions for future research to better identify optimal PA promotion strategies and eventually, the overall health of our youth.

## METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement guided this systematic review (22). This review was registered in the international prospective register of systematic reviews (PROSPERO; CRD42020211741) on November 12, 2020.

### *Search Strategy*

PubMed, Web of Science, and SPORTdiscus were searched on February 10, 2023, by primary reviewer (MW) using combinations of the following terms: (physical activity OR activity) AND (timing OR temporal patterns OR patterns) AND (youth* OR children* OR child* OR adolescent*) AND (day-to-day OR weekday OR weekend). When possible, the search was filtered for human studies, but no date restriction was included, meaning that results encompassed all articles published up until April 2022. Reference "snow-balling" by reviewing bibliographies of eligible studies was also utilized to identify articles appropriate for inclusion in this review. Additionally, a search of ProQuest was conducted to identify any existing gray literature (abstracts, conference proceedings) concerning temporal patterns of PA in youth.

### *Selection of Studies*

Inclusion criteria were that the study (a) included human subjects aged 4–17 years, (b) specifically reported on timing or temporal patterns of physical activity in the results, and (c) was published by February 2023. Exclusion criteria included (a) article not being available in English, (c) narrative or systematic review paper, and (d) no full-text article was available (e.g., only a conference abstract).

Initial study selection was performed in Microsoft Excel; duplicates were removed from the exported search results from the 3 databases. The remaining studies were screened by title,

then abstract. Potentially eligible studies then underwent full text review by two independent reviewers (MW and DV). Inter-rater reliability was assessed after each step by both percent agreement (97%) and Cohen's Kappa (k=0.84). Percent agreement was defined as both reviewers agreeing on the inclusion or exclusion of a particular article and was calculated at each step with a minimum agreement of 80% between reviewers. All discrepancies were resolved between the two reviewers before continuing with the next step.

***Data Extraction***

Study data were extracted in duplicate by both reviewers (MW and DV) using a standardized data-extraction form. Study characteristics (e.g., design, setting, type of PA measurement (e.g., accelerometer, pedometer, direct observation), definition of time-period or pattern, number of days, and duration of data collection) were recorded. Study setting and location was recorded (e.g., 10 public schools in East Lansing, MI). Additionally, sample size and participant characteristics such as number of subjects, sex, age range, school-grade range etc., were extracted.

Further information was extracted regarding specific patterns examined within the broader topic of temporal patterns of PA (e.g., within-day PA, day-day PA, longitudinal PA longer than one year, compensation, synergy etc.). Once the pattern/time-period of focus for each article was determined, we recorded results (e.g., results suggested evidence/no evidence for compensation). In addition to observed patterns in each article, we recorded sub-group differences and other factors that may have influenced patterns in PA frequency, duration, or intensity (e.g., sex, age, race, school, or other active events).

### *Risk of Bias Assessment*

All studies included in this review were assessed for bias using the National Heart, Lung, and Blood Institute's (NHLBI) Study Quality Assessment Tool for Observational Cohort or Cross-sectional studies.[25] The assessment was completed for each article by the same two independent raters (MW and CV). The study quality assessment tool has a set of 14 questions relevant to the study design (See APPENDIX A). Questions answered with a *YES* received a score of 1, questions answered with a *NO* or *NR* (not reported) or *CD* (cannot determine), received a score of 0. Discrepancies or disagreements between raters (MW and CV) on either the answers to assessment tool questions or final ratings were taken to a 3rd author (KP) for adjudication. The final study quality rating was based on the following total scores: Good (11–14), Fair (6–10), or Poor (0–5). The ratings on the different items were used by the reviewers to assess the risk of bias in the study due to flaws in study design or implementation. In general, a study rated "good" had the least risk of bias, and results should be considered valid. A study rated as "fair" was susceptible to some bias but not enough to invalidate its results, and a study rated "poor" indicated significant risk of bias.[25]

## RESULTS

### *Selection of Studies*

The literature search (as outlined by Figure 2.1) resulted in 6,137 articles identified. Thirty of the 6,193 were included in the final study selection. Following the original search, articles were removed as duplicates (n=2,127), after screening by title (n=4,066), after screening by abstract (n=152), and after screening by full text (n=28). After the screening process, we were left with a total of 31 articles to be assessed by this systematic review. (Figure 2.1)

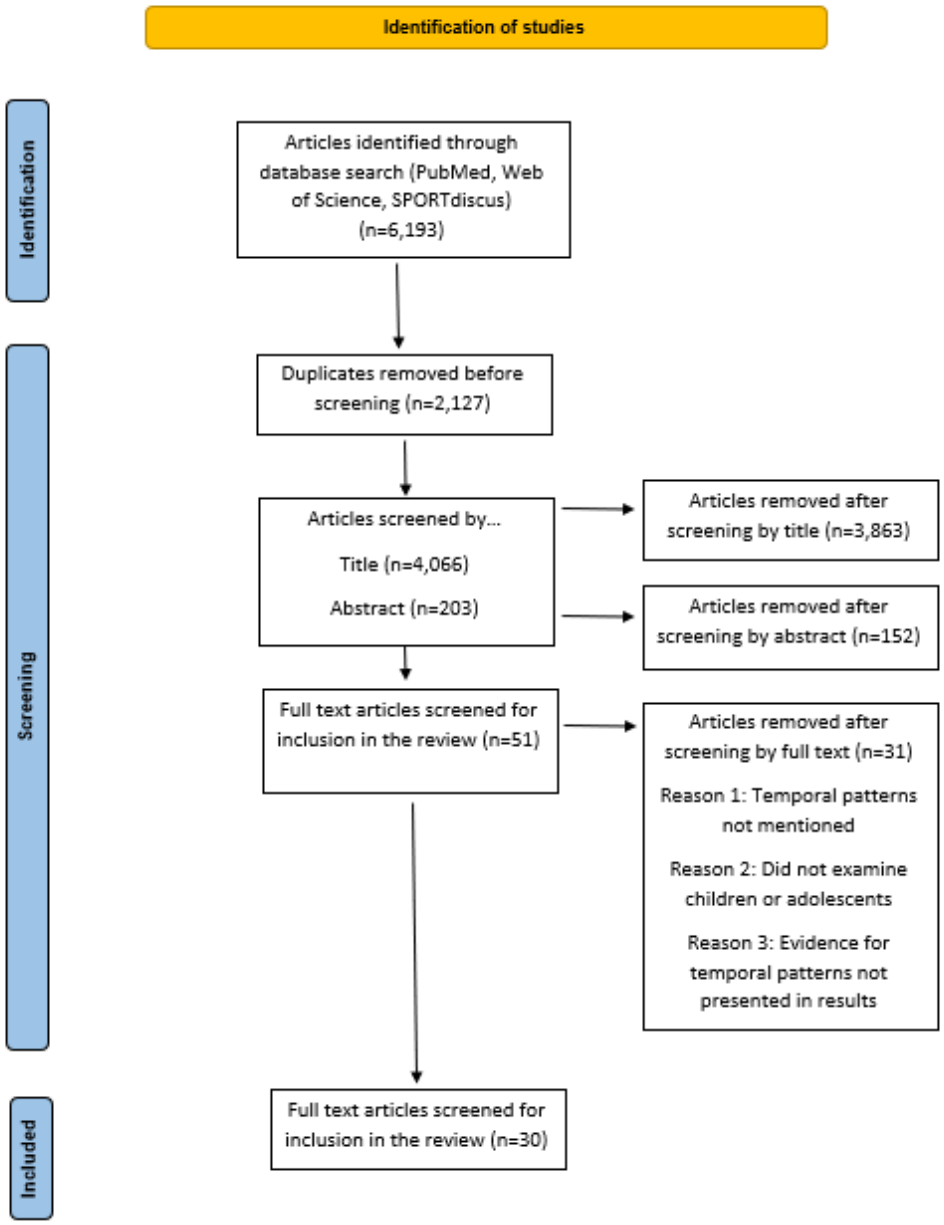


**Figure 2.1: Prisma Flowchart of Database Search and Study Selection**

***Study Designs and Settings***

Table 2.1 provides an overview of temporal pattern/time-period assessed in each article. More detailed information regarding study design, setting, sample description, and method of PA measurement is provided in Supplementary Table 1. The large majority of studies included just

children (6–11 years; n=22, 73.3%) and just adolescents (12–17 years; n=2, 6.7%), or both children and adolescents (n=6; 20%). The distribution of different temporal patterns assessed includes within-day PA (n=16; 53.3%), day-to-day PA (n=12; 40%), longitudinal PA (n=2; 6.5%), weekday PA (n=2;6.5%), weekday vs. weekend (n=15; 50%), found evidence for compensation (n=8; 26.7%), and synergy (n=8; 26.7%) (Supplementary Table S.1). It is worth noting that these patterns are not mutually exclusive and were often examined together in the same study. For example, most studies examining compensation or synergy often examined within-day or day-to-day patterns as well. Furthermore, it must be noted that many of the included studies did not have the purpose of examining temporal patterns and did not state evidence for compensation/synergy in their results. Evidence for specific patterns was deduced from study results by reviewer MW.

**Table 2.1: Overview of Temporal Pattern/Time-Period Assessed**

| | **Type of Temporal Pattern Assessed** | | | | | | |
|---|---|---|---|---|---|---|---|
| **STUDY** | **WD** | **DD** | **L** | **WKD** | **WVW** | **Evidence for COMP** | **Evidence for SYN** |
| Bagget, 2010 | **X** | **X** | | | | | **X** |
| Beighle, 2012 | | **X** | | | | **X** | |
| Brusseau, 2011 | | **X** | | | **X** | **X** | |
| Comte, 2012 | | | | | **X** | | |
| Dale, 2000 | **X** | | | | | | **X** |
| De Baere, 2015 | **X** | | | | | | |
| Fairclough, 2007 | **X** | **X** | | **X** | | | |
| Fairclough, 2012 | **X** | | | | | | **X** |

**Table 2.1 (cont'd)**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fairclough, 2015 | | | | | **X** | | **X** |
| Fremeaux, 2011 | **X** | | | | | **X** | |
| Gavarry, 2000 | | **X** | | | | **X** | |
| Gidlow, 2008 | **X** | | | | **X** | **X** | |
| Goodman, 2011 | | | | | **X** | | **X** |
| Harmon, 2013 | | **X** | | | **X** | **X** | |
| Long, 2013 | **X** | | | | | | **X** |
| Matthews-Ewald, 2014 | **X** | | | | | | **X** |
| Mota, 2003 | **X** | | | **X** | | | |
| Nader, 2008 | | | **X** | | **X** | | |
| Nilsson, 2009 | **X** | **X** | | | **X** | | |
| Pau, 2017 | **X** | | | | **X** | | |
| Ridgers, 2014 | | **X** | | | | **X** | |
| Ridgers, 2018 | | **X** | | | | **X** | |
| Rowlands, 2008 | | | | | **X** | | |
| Saunders, 2014 | **X** | | | | | | |
| Sigmundova, 2016 | | | | | **X** | | |

**Table 2.1 (cont'd)**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Steele, 2010 | **X** | | | | **X** | | |
| Saint-Maurice, 2018 | **X** | **X** | | | **X** | | |
| Telford, 2013 | | **X** | **X** | | **X** | | **X** |
| Vincent, 2017 | | **X** | | | | | |
| Wilkin, 2006 | | | | | **X** | | |
| **NUMBER OF STUDIES** | **16** | **12** | **2** | **2** | **15** | **8** | **8** |

*WD=within-day, DD=day-to-day, L=longitudinal, WKD=weekday only, WVW=weekend vs weekday, COMP=compensation, SYN=synergy

***Risk of Bias***

Our analysis revealed that all articles were scored as either "Fair" or "Good". Of the 30 articles examined, 22 (73.3%) were scored as "Fair" (total score = 6–10). Eight articles (26.7%) were scored as "Good" (score 11–14).

***Compensation/Synergy***

Of the selected articles (n=30), 8 (26.7%) found evidence for PA compensation [2,4,11,12,13,16,32,33] (Table 2.2) and 8 (26.7%) found evidence for PA synergy (Table 2.3). [1,6,8,9,14,19,21,42] Studies which found evidence of PA compensation included 11, who concluded that the PA of children seemed to compensate in their PA behavior. Gidlow et al., 2008 examined a sample of 503 children and adolescence (250 boys, 253 girls), ages 3–16, attending 9 primary and 2 secondary schools and found that PA, as accelerometer counts per minute, was lower in school versus out of school (in school: 437.2 $\pm$172.9; out of school: 575.5 $\pm$ 202.8; P<0.001). Ridgers et al. 2014 found that on any given day, every additional 10 minutes spent in

MVPA was associated with approximately 25 min less LPA and 5 min less MVPA the following day.

**Table 2.2: Studies finding evidence for PA Compensation**

| ***Study*** | ***Participants*** | ***Type of PA Assessment*** | ***Summary of Results*** |
|---|---|---|---|
| **Beighle et al., 2012** | 112 children in 3rd-5th grade | Pedometer | Children compensated for low step count during school time with higher step count during the after-school period. |
| **Brusseau et al., 2011** | Three hundred and sixty-three children (8-11 years old) from six Southwestern USA elementary schools | Pedometer | During weekdays, the fourth and fifth grade children averaged 13,196 ± 3,334 and 11,295 ± 3,168 steps/day for boys and girls, respectively. This is compared to a weekend average of 7,660 ± 4,647steps/day (boys) and 7,317 ± 4,062 steps/day (girls). Indicating day-to-day compensation between weekdays and weekend days. |
| **Fremeaux et al., 2011** | 206 children (115 boys, aged 8-10 years) from 3 primary schools in South-West England | Actigraph Accelerometers | Significant differences found between in-school and out-of-school PA. Concluded that the PA of children seems to compensate in such a way that more activity at one time is met with less activity at another. |
| **Gavarry et al., 2000** | One hundred eighty-two French schoolchildren and teenagers from primary school, junior high school, and high school | Heart Rate Monitor | Male and female subjects were more inactive during free days and less active during school days ($P < 0.05$). Compensating for low activity during school with higher levels of PA during free days. |

**Table 2.2 (cont'd)**

| | | | |
|---|---|---|---|
| **Gidlow et al., 2008** | Random sample of children (250 boys, 253 girls) aged 3-16 years attending nine primary and two, secondary schools | Actigraph Accelerometer | Physical activity was lower in-school than out-of-school. Approximately half of the **children** with the lowest in **school activity** compensated **out** of **school** durin g the week (47.4%) and about one-third at the weekend (30.0%). |
| **Harmon et al., 2013** | 39 inner-city children (10.5 ± 0.61 years old) | Pedometer | Children were significantly more active during the week and less active during the weekend. Indicating Day-to-day compensation from school days to weekend days. |
| **Ridgers et al. 2014** | Two hundred and forty-eight children (121 boys and 127 girls) age 8-11 yrs. from nine primary schools in Melbourne, Australia | Actigraph Accelerometer | On any given day, every additional 10 min spent in MVPA was associated with approximately 25 min less LPA and 5 min less MVPA the following day. |
| **Ridgers et al., 2018** | One hundred and twenty-seven children (8-11 years) | Actigraph Accelerometer | On any given day, every additional 10 minutes spent in moderate-to-vigorous physical activity (MVPA) was associated with 9.3 minutes less MVPA the following day. |

Studies which found evidence for PA synergy include Dale et al., 2000, who found that 78 third- and fourth-grade children (40 girls and 38 boys; Mage = 9.3 years, SD= .68) from a private elementary school did not compensate, but in fact, were synergistic in their PA and exhibited higher levels of PA after a more active day vs. a PA restrictive school day. Long et al., 2013, examined youth, aged 6–19 years from the National Health and Nutrition Examination Surveys (NHANES) and found that each additional minute of school-day MVPA accumulated

was associated with an additional 1.14 minutes (95% CI=1.04, 1.24; p<0.001) of total daily MVPA, or 0.14 additional minutes (95% CI = 0.04, 0.24; p=0.008) outside the school day. Goodman et al., 2011 examined British children ages 8–13 from Hertfordshire, South-East England from 9 schools and found that on week- and weekend days, each extra 1% of time in PE/games, school breaks, school active travel, non-school active travel, structured sports, and out-of-home play predicted a 0.21 to 0.60% increase in the proportion of the day in MVPA.

**Table 2.3: Studies finding evidence for PA Synergy**

| Study | Participants | Type of PA Assessment | Summary of Results |
|---|---|---|---|
| **Bagget et al., 2010** | 6916, 8th grade girls from the Trial of Activity for Adolescent Girls (TAAG) | Actigraph Accelerometer | For every one MET-minute more of inactivity, there was 3.18 MET-minutes (95% confidence interval (CI): −3.19, −3.17) less of TPA (activity >2 METS) on the same day. Daily inactivity was also negatively associated with TPA on the following day. Each additional minute of MVPA was associated with 1.85 min less of inactivity on the same day (95% CI: −1.89, −1.82). Daily MVPA was also negatively associated with inactivity the following day. Children did not compensate but were synergistic in their PA. |
| **Dale et al., 2000** | Seventy-six 3rd and 4th grade children | CSA Accelerometer | Dependent t tests revealed that children did not compensate for a sedentary school day by increasing their levels of physical activity after school. In fact, average movement counts per minute were higher in the 3 p.m. - 7:30 p.m. period following the active day (525 counts.min-1) versus the restricted day (196 counts.min-1). |
| **Fairclough et al., 2012** | Two hundred and twenty-three children (10.7 ± 0.3 yrs) from 8 north-west England primary schools | Actigraph Accelerometer | Highly active children achieved significantly more moderate PA and vigorous PA than less active children during four of the five segments of the school day. |

**Table 2.3 (cont'd)**

| | | | |
|---|---|---|---|
| **Fairclough et al., 2015** | 810 English children (n = 420 girls) aged 10–11 years | Actigraph Accelerometer | The most active children maintained their sedentary time and physical activity levels from weekdays to weekends. |
| **Goodman et al., 2014** | 345 British children (8–13 years) | Activity Diaries<br><br>RT3 Accelerometers | Each 1% increase in weekday non-school active travel predicted 0.38% more time in MVPA at other times (95% CI 0.18, 0.58), reflecting evidence for activity synergy. |
| **Long et al., 2013** | 2,548 youth aged 6–19 years from 2003–2004/2005–2006 National Health and Nutrition Examination Surveys | Actigraph Accelerometer | Each additional minute of school-day MVPA was associated with an additional 1.14 minutes (95% CI=1.04, 1.24; p<0.001) of total daily MVPA, or 0.14 additional minutes (95% CI=0.04, 0.24; p=0.008) outside the school day, controlling for total daily accelerometer wear time and age, gender, race/ethnicity, and other non–time varying covariates. |
| **Matthews-Ewald et al., 2014** | 268 9th and 10th grade students enrolled in physical education classes in a rural state | Actigraph Accelerometer | Adolescents who engage in high levels of light physical activity tend to do so regardless of class environment (i.e., PE or non-PE classes). This maintenance of PA levels suggests synergy. |
| **Telford et al., 2013** | 853 children (starting age ~8 years) recruited from 29 Australian elementary schools | Pedometer<br><br>Actigraph Accelerometer | Data show that the volume of steps taken per day fluctuated from year to year and that there was no evidence of either a systematic increase or decline in volume of PA from age 8 to 12 years. This maintenance over time suggests synergy. |

***Within-Day/Day-to-Day/Longitudinal Studies***

Of the 30 selected articles, 16 (53.3%) examined within-day PA patterns. De Baere et al., 2015, examined 211 children aged 10–14, from 15 primary and 15 secondary schools and found that for PA during different time segments in the day, physical activity level was highest during

the early evening (average of 2.51 METS) and school hours (average of 2.49 METS); the late evening segment was significantly less active (average of 2.21 METS). Similarly, Mota et al., 2003, found sex differences in within-day PA. After examining 84 subjects (boys, n = 30; girls, n = 54), age 8–15 years old they found that girls exhibited a higher percentage of time engaged in MVPA during the morning and early afternoon periods, while boys engaged in MVPA at a higher percentage during the late afternoon and evening periods.

Twelve (40%) of the 30 articles examined day-to-day patterns, many of which also compared PA during weekdays versus PA during weekends (n=16, 53.3%). For example, Brusseau et al., 2011, examined step counts of inner-city children and found that the weekday step count mean was 10090 ± 2939 and the weekend step count was 7557 ± 4337, showing that these children were significantly more active during the week ($p = 0.03$). Similarly, Nilsson et al., 2009, found that in their examination of 1,954 European children, ages 9 and 15 years old, the proportion of children accumulating 60 min of MVPA was higher during weekdays compared with weekend days. Comte et al., 2012, also found that youth are not as active on weekends as they are on weekdays. For 626 Canadian youth, ages 10–15, compared with weekdays, MVPA was 30% lower than weekend days (55.8 ± 23.0 min vs. 38.7 ± 26.7 min; $p < 0.001$), whereas light PA was 15% higher.

Only two (6.7%) of the 30 included studies examined longitudinal temporal patterns of PA. Telford et al., 2013, examined youth PA in 853 children from twenty-nine Australian elementary schools, seven days each year for five consecutive years, and found that a consistent daily pattern of pedometer step counts in MVPA, and LPA emerged during each year, characterized by increases on school days, from Monday to Friday, followed by decreases on the weekends. These patterns persisted through to age 12. Nader et al., 2008, also examined

longitudinal temporal PA patterns for 1,032 youth from the National Institute of Child Health and Human Development Study of Early Child Care and Youth Development and found that PA declined significantly between ages 9 and 15 with weekday MVPA decreasing by an average of 38 minutes per year and weekend MVPA decreasing by an average of 41 minutes per year.

***Group Differences***

The clearest and most examined differences in temporal patterns of PA for youth in this review exist between sexes. Mota et al. 2010. examined temporal patterns of PA amongst boys and girls aged 8–15 years old and, as summarized in the previous section, found that girls showed a higher percentage of time engaged in MVPA during both the morning and early afternoon time-periods, while boys spent a higher percentage of time engaged in MVPA during the late afternoon and evening periods. They concluded that, in general, girls were more active during the school day while boys were more active during the after-school period. Comte et al. 2013 also found that sex-specific differences in MVPA is more clearly seen on weekdays than on weekend days (~13 vs ~8 min per day; $p < 0.01$).

Age differences in temporal patterns have also been examined. Telford et al. 2013 examined children starting at 8 years old and followed them for 5 full years into adolescence. Participants wore a pedometer for 7 straight days once each year and accelerometers concurrently in the last two years to examine PA volume (accelerometer counts (AC) per day), MVPA, light PA (LPA) and sedentary time (SED). They found that, although there was a trend for decreasing MVPA and increased SED over the 5-year period, there was a consistent daily pattern in pedometer step counts, accelerometer counts, and MVPA that persisted with increases on school days (Mon–Friday) and decreases on weekends (Sat–Sun). Friday was found to be the most active day while Sunday was found to be the least active day. There is very little evidence

to further suggest existing disparities in temporal patterns of PA such as by race/ethnicity, weight status, fitness level, and socioeconomic status.

## DISCUSSION

The promotion of PA in youth is important, as previous research shows that PA behavior developed during childhood transfers into adulthood.[41] Many promotional strategies have been used to improve youth PA behavior, such as school- and home-based PA interventions, and encouragement of participation in youth sports, PE programs, and after-school programs Not many of these strategies, however, have incorporated knowledge of how temporal patterns of PA may help to increase overall PA. Studies examining temporal patterns of physical activity have examined different populations, age groups, study settings, patterns, and time-periods and therefore, have found very heterogeneous results. To date, there seems to be no strong agreement among researchers as to a clear-cut temporal pattern of physical activity that all youths follow. As youth PA is extremely variable by nature, nurture, and circumstance, and seems to be highly dependent on the individual's school day activities, there may never be a set pattern that fits all youth.

A key issue in this topic of research seems to be the overall lack of agreement between researchers regarding PA compensation and PA synergy. As demonstrated in this review, there are existing studies to support both arguments, but none present conclusive evidence for one or the other. This lack of agreement may be due to the varying methods of physical activity assessment, study settings, age groups and time-period/pattern of interest, but it also may simply be due to the variability of physical activity patterns of youth, which is in many cases dependent on activities during the day and week that are planned for them. It is also a possibility that both compensation and synergy occur but are dependent on the individual, the setting, the season, and

planned events during the day. Additionally, studies examined in this systematic review may not have followed youth for a sufficient period to clearly identify habitual PA patterns. Therefore, additional research is necessary over longer observation periods with examination of differences between race/ethnicities, ages, and fitness levels if we are to truly understand the temporal patterns of PA that youth follow. More extensive knowledge of which PA patterns do or do not exist will provide valuable information for health promoters, educators, and researchers. Researchers could use more information regarding PA patterns to identify time periods to target for interventions and other health programming. For example, if we determine that youth are always less active following an active event during the day like PE or recess, classroom teachers could encourage more activity in their classroom following these times. The main goal is to increase overall physical activity and help youth transition into active and healthier adults.

Existing literature has shown that youth are more active on weekdays than on weekends. However, youth are still getting the majority of weekday PA during the after-school period.[7,18] An area of concern, then, becomes how to increase PA during the actual school day. Schools continue to face increased pressure to improve student performance in standardized test scores for STEM subjects, and consequently there has been a considerable decline in opportunities for regular physical activity instruction during the school day.[26] This presents unique challenges for PA researchers.

A possible way to address these challenges is to examine temporal patterns of PA during in-school-based PA interventions and programs. There may be many opportunities to integrate meaningful bouts of PA to normally sedentary classroom activities to help youth meet PA guidelines. Measurement and observation of PA interventions during the school day may lead to

a more accurate representation of overall PA patterns over the course of days, weeks, and months.

Having stated the above challenges, these changes in our education system, and a trend toward a more sedentary school day, have led to the proliferation of after-school physical activity programs and interventions, which seem to be effective in increasing overall PA levels. Trost et al, 2008 found that, on average, youth accumulated 20.3 minutes of MVPA during a 2.5-hour long afterschool program (over 33% of the recommended PA recommendation of 60 minutes a day). This increase in MVPA during a targeted part of the day for a large group of students allows researchers to examine PA not only during the after-school programs, but also during the time periods before and after the programs to see if youth react in more compensational or synergistic manners in response to periods of elevated PA.[46]

Although the phenomenon of schools eliminating PE which leads to youth generally not meeting PA requirements seems discouraging, studies highlighted in this systematic review show that in many cases youth compensate for PA time lost during the school day with increased PA during afterschool time. [2,4,12,16,32,33] In contrast, some research posits some evidence that youth who maintain higher levels of PA throughout the school day act synergistically, maintaining that high level of PA throughout the rest of the day and into future days, weeks, months, and years. [1,6,8,9,14,19,21,42] Either way it seems that youth strive to be active even in the face of large barriers to PA such as the school day and other planned sedentary activities. Generally speaking, interventions during and after the school day are valuable to increasing the overall PA of youth. More research is needed to find the most effective interventions during those times.

### *Study Limitations*

Although this systematic review closely followed PRISMA guidelines, it has limitations. It is possible that qualifying literature, particularly in languages other than English, may have been excluded from this systematic review. While multiple searches of ProQuest were completed to identify any gray literature on the topic of temporal patterns of PA in youth, none were found. Unpublished works may also have been missed by our review process.

### *Future Studies*

In conclusion, literature examining the temporal patterns of PA in youth is highly variable in terms study setting, age group examined, and type of temporal patterns examined and found. It is clear, however, that the school day plays an important role in dictating the PA patterns of youth throughout the days and weeks. In most studies examining children, a largely sedentary school day presents a challenge for classroom teachers, PE teachers, and researchers in the promotion of PA and the planning of active events during the day. If we can find new and innovative ways to navigate and/or moderate this significant and time-consuming barrier to PA behavior, we may be able to help our youth be more active, meet the PA recommendations, and be healthier overall. Limitations of the current literature include short study durations and small sample sizes, little to no examination of individual and group factors that may influence temporal patterns, and little examination of how certain active events during the day and especially during school time may influence physical activity patterns.

To address these limitations, future studies examining temporal patterns of PA in youth should aim to; 1) examine the effect of existing school programming and scheduling on temporal patterns of PA, 2) examine temporal patterns of PA in response to school-based interventions, 3) examine temporal patterns of PA in both younger and older and older age groups, 4) examine

temporal patterns of PA over longer study durations and in larger sample sizes, 5) examine differences in temporal patterns of PA for different sexes, races/ethnicities, and socioeconomic status, 6) Examine temporal patterns of PA with respect to the influence of active events during the day (i.e.PE class, youth sports, after-school programming), and 7) explore new ways to promote PA at all time points during the days, weeks, months, and seasons.

More studies examining these topics would lend valuable information and insight into which youth (sex, age, race, ethnicity), which specific time-periods, and which planned activities (i.e., PE, youth sports, after-school programs) should be focused on for the promotion of youth PA. All this should be done with the goal of creating a healthier youth population who transition into healthier adults.

**Table S.1: Study Details Including Study Design, Participants, Patterns Assessed, and Evidence for Compensation or Synergy**

| Study | Study Design | Study Setting | Participants | Patterns Assessed | Risk of Bias Score |
|---|---|---|---|---|---|
| **Bagget, 2010** | Observational/ Cross-Sectional | Schools | 6,916 8th grade girls | Within-Day PA, Day-to-Day PA, and Compensation | 8/14 (Fair) |
| **Beighle, 2012** | Observational/ Cross-Sectional | Schools | 105 children, mean age 8.9 years (65 girls and 40 boys) | Longitudinal, Day-to-Day PA and Compensation | 7/14 (Fair) |
| **Brusseau, 2011** | Observational/ Cross-Sectional | Schools | 363 children aged 8-11 years (160 boys and 203 girls) | Day-to-Day PA, Compensation, and Weekday vs. Weekend | 8/14 (Fair) |
| **Comte, 2012** | Observational/ Cross-Sectional | Schools | 626 youth (aged 10–15 years) 60% girls | Weekday vs. Weekend | 9/14 (Fair) |
| **Dale, 2000** | Observational/ Cross-Sectional | Schools | 76 3rd and 4th grade children 40 girls 38 boys | Within-Day PA, Compensation | 9/14 (Fair) |
| **De Baere, 2015** | Observational/ Cross-Sectional | Schools | 122 boys and 119 girls aged between 10 and 14 years | Within-Day PA | 10/14 (Fair) |
| **Fairclough, 2007** | Observational/ Cross-Sectional | Schools | 58 kids, 31 boys, aged 7-11 years | Within-Day PA, Day-to-Day, and Weekday only | 10/14 (Fair) |
| **Fairclough, 2012** | Observational/ Cross-Sectional | Schools | 223 children mean age 10.7 years (138 girls, 85 boys) | Within-Day PA and Synergy | 11/14 (Good) |
| **Fairclough, 2015** | Observational/ Cross-Sectional | Schools | 810 children aged 10-11 years (420 girls, 390 boys) | Weekday vs. Weekend and Synergy | 7/14 (Fair) |
| **Fremeaux, 2011** | Observational/ Cross-Sectional | Schools | 206 children (115 boys) aged 8-10 years | Within-Day PA, Compensation | 11/14 (Good) |
| **Gavarry, 2000** | Observational/ Cross-Sectional | Schools | 182 school children and teenagers (age 6–20 yr) | Day-to-Day PA | 9/14 (Fair) |
| **Gidlow, 2008** | Observational/ Cross-Sectional | Schools | children (250 boys, 253 girls) aged 3-16 years | Within-Day PA, Compensation | 10/14 (Fair) |

**Table S.1 (cont'd)**

| | | | | | |
|---|---|---|---|---|---|
| **Goodman, 2011** | Observational/ Cross-Sectional | Schools | 345 children aged 8-13 years | Weekday vs. Weekend, Compensation, and Synergy | 7/14 (Fair) |
| **Harmon, 2013** | Observational/ Cross-Sectional | Schools | 18 boys, 14 girls mean age 10.5 years | Day-to-Day PA, Weekday vs. Weekend | 10/14 (Fair) |
| **Long, 2013** | Observational/ Cross-Sectional | Schools/ NHANES | 2548 children aged 6-19 (1266 boys and 1282 girls) | Within-Day PA and Compensation | 9/14 (Fair) |
| **Matthews-Ewald, 2014** | Observational/ Cross-Sectional | Schools | 166 9th and 10th grade students (approx. equal males and females) | Within-Day PA, Compensation | 9/14 (Fair) |
| **Mota, 2003** | Observational/ Cross-Sectional | Schools | 84 subjects (30 boys and 54 girls) , age 8–15 years | Within-Day PA and Weekday vs. Weekend | 8/14 (Fair) |
| **Nader, 2008** | Observational/ Cross-Sectional | Schools | 517 boys and 515 girls ages 9-15 years | Longitudinal PA and Weekday vs. Weekend | 9/14 (Fair) |
| **Nilsson, 2009** | Observational/ Cross-Sectional | Schools | 1,954 children and adolescents, ages 9 and 15 year-olds | Within-Day PA, Day-to-Day PA, and Weekday vs. Weekend | 9/14 (Fair) |
| **Pau, 2017** | Observational/ Cross-Sectional | Schools | 76 boys and 93 girls age 8.6 +/- 1.5 years | Within-Day PA and Weekday vs. Weekend | 9/14 (Fair) |
| **Ridgers, 2014** | Observational/ Cross-Sectional | Schools | 248 children ages 8–11 years (121 boys and 127 girls) | Day-to-Day PA and Compensation | 10/14 (Fair) |
| **Ridgers, 2018** | Observational/ Cross-Sectional | Schools | 127 children, 8-11 years old | Day-to-Day PA and Compensation | 11/14 (Good) |
| **Rowlands, 2008** | Observational/ Cross-Sectional | Schools | 84 children, aged 9–11 years (45 boys, 39 girls) | Weekday vs. Weekend | 8/14 (Fair) |
| **Saunders, 2014** | Experimental | Schools | 20 adolescents, aged 10-14 years (12 boys, 8 girls) | Within-Day PA, Compensation | 11/14 (Good) |
| **Sigmundova, 2016** | Observational/ Cross-Sectional | Schools | 194 kindergartners, aged 4-7 years | Weekday vs. Weekend | 12/14 (Good) |
| **Steele, 2010** | Observational/ Cross-Sectional | Schools | 1568 children aged 9-10 years, 701 boys and 867 girls | Within-Day PA and Weekday vs. Weekend | 11/14 (Good) |

**Table S.1 (cont'd)**

| | | | | | |
|---|---|---|---|---|---|
| **ST. Maurice,** | Observational/ Cross-Sectional | Homes/ Schools | 135 elementary, 67 middle, and 89 high-school students (128 boys and 163 girls) | Within-Day PA, Day-to-Day PA, and Weekday vs. Weekend | 11/14 (Good) |
| **Telford, 2013** | Observational/ Cross-Sectional | Schools | 853 children, approximately 8 years old (435 boys 418 girls) | Day-to-Day PA, Longitudinal PA, and Weekday vs. Weekend | 10/14 (Fair) |
| **Vincent, 2016** | Observational/ Cross-Sectional | Schools | 458 children, aged 8-11 years old | Day-to-Day PA | 11/14 (Good) |
| **Wilkin, 2006** | Observational/ Cross-Sectional | Schools | 137 girls, 170 boys, 4-9 years old | Weekday vs. Weekend | 9/14 (Fair) |

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## APPENDIX A: NIH STUDY QUALITY ASSESSMENT TOOL FOR OBSERVATIONAL AND CROSS-SECTIONAL STUDIES

| Criteria | Yes | No | Other (CD, NR, NA) * |
|---|---|---|---|
| 1. Was the research question or objective in this paper clearly stated? | | | |
| 2. Was the study population clearly specified and defined? | | | |
| 3. Was the participation rate of eligible persons at least 50%? | | | |
| 4. Were all the subjects selected or recruited from the same or similar populations (including the same time)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants? | | | |
| 5. Was a sample size justification, power description, or variance and effect estimates provided? | | | |
| 6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured? | | | |
| 7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed? | | | |
| 8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)? | | | |
| 9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants? | | | |
| 10. Was the exposure(s) assessed more than once over time? | | | |
| 11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants? | | | |
| 12. Were the outcome assessors blinded to the exposure status of participants? | | | |
| 13. Was loss to follow-up after baseline 20% or less? | | | |
| 14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)? | | | |

| **Quality Rating (Good, Fair, Poor)** |
| --- |
| Rater #1 Initials: |
| Rater #2 Initials: |
| Additional Comments (If POOR, please state why): |

*CD, cannot determine; NA, not applicable; NR, not reported

**Chapter 3: Manuscript 2**

# School-Day Temporal Patterns of Physical Activity in a Racially Diverse, Low SES Sample of Adolescent Girls

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**ABSTRACT**

**Introduction:** The importance and benefits of regular habitual activity are well known. Previous research has identified the school day as a period of interest and a target for increasing PA among school age youth. One avenue for researching PA during the school day is to examine temporal patterns of PA, the concept that youth follow distinct and identifiable patterns over the days, weeks, months and seasons. **Purpose:** The purpose of this study was to identify existing temporal patterns during the school day as well as different participant characteristics that may be associated with higher levels of PA of girls in urban, low SES areas with a high percentage of racial/ethnic minorities during the Girls on the MOVE (GOTM) after-school PA intervention. **Methods:** The full GOTM data set (n=1519) was used to observe girls' temporal patterns during the baseline time-point. One week of PA was measured via Actigraph accelerometers at baseline. Days in this week of data collection were split into "before-school time", "during- school time", "after-school time", and "evening time" to examine within-day patterns. **Results:** Kendall's tau revealed significant correlations ($p<0.001$) for average MVPA min/hr between all four time periods, with the strongest correlation occurring between after-school and evening time periods ($f=0.563$, $p<0.001$), and the weakest correlation occurring between before-school and evening time periods ($f = 0.177$, $p<0.001$). Overall average MVPA min/hr was highest during the before-school period (6.11 min/hr). It dropped during school-time hours to 2.98 min/hr, and then rose again during the after-school and evening periods (5.27 min/hr, 4.84 min/hr, respectively). before school, age was significantly and positively related to average MVPA min/hr ($p<0.001$) **Conclusion:** Temporal patterns of PA in girls remains unclear. Like previous research, results suggest that youth PA patterns are highly variable. In general, average MVPA rose and fell in a compensatory manner throughout the school day, although it is not clear if this is a habitual

pattern or due to structured schedule of the school day. Further research is needed if we are to accurately characterize the patterns that youth follow in their PA behavior.

## INTRODUCTION

Participation in regular, habitual physical activity (PA) is accompanied by many important health benefits, such as improved bone health and weight status for children 3–5 years old, improved cognitive function for children ages 6–13 years old, reduction in risk of all-cause and disease-specific mortality, improved physical function, and overall improved quality of life for all ages.[1] These benefits are especially important for children under the age of 12, with research suggesting that PA behaviors developed during childhood likely track into adulthood.[2] Despite these benefits, surveillance studies suggest that less than 50% of U.S. children and adolescents meet public health recommendations for PA.[3,4]

School-day physical activity (PA) has long been a time period of interest and a target of health promotion and PA interventions because the school setting is where most children spend a significant amount of their time during the week.[23] School communities are able to drastically impact the PA of youth, either by helping students work toward the recommended 60 minutes of moderate to vigorous physical activity (MVPA) per day, or by keeping them primarily sedentary in a typical classroom environment.[1] Currently in the United States, only 45% of children and adolescents across all school levels participate in regular PA breaks during the day, outside of physical education class.[5] Only 11% of elementary schools, 8% of middle schools, and 2% of high schools require regular physical activity breaks for youth during the school day, despite the fact that PA breaks could benefit youth by increasing overall physical activity and improving classroom behavior and academic performance.[5] Examining temporal patterns of PA in youth during and across school days could identify times during the day and/or week that could be targeted for PA promotion.

Temporal patterns of PA can be viewed over the course of a day, week, month, season, or other time-period. Many different patterns may exist for youth PA, such as within-day, day-to-day, week-to-week, seasonal, or even longitudinal patterns that can be tracked from childhood to adulthood. Much of the existing literature examining temporal patterns explore one or multiple of these patterns with great variability in participant demographics, age ranges, study settings, and study duration, however, there are two relevant physical activity patterns that have been previously identified in the literature. The first, PA compensation, suggests that youth compensate for increased PA during one part of the day by decreasing their PA in another part of the day (or vice versa) in order to maintain an innate total amount of PA.[6] The other is PA synergy, a pattern which suggests that youth do not compensate, but rather, build on times of high (or low) PA with additional periods of high (or low) PA.[7] Current literature lacks definitive evidence, however, to suggest which of these patterns occurs most often or if both occur dependent on the individual and situation. Although examination of long-term patterns may seem more prudent for helping youth become healthy adults, more information regarding short-term (within-day) patterns may aid in improving promotional efforts to increase the total, daily PA of youth.

In addition to a thorough characterization of temporal patterns, it is important to examine individual characteristics that may be related to children's physical activity during the school day such as body fat percentage, cardiorespiratory fitness (CRF), race/ethnicity, and age. For example, Ruiz et al., (2006) found that in a sample of 780 children aged 9–10 years, lower body fat and higher CRF was significantly associated with higher participation in vigorous PA (VPA).[21] Another examination of 375 students in grades 1–12 by Trost et al., (2002) revealed that amounts of daily MVPA and VPA had a significant inverse relationship with grade

level/age, with the largest decline occurring between grades 1–3 and 4–6. The authors concluded that these results support the rapid decline of PA during childhood and adolescence.[20] Furthermore, in a study by Belcher et al., (2010), differences in PA by race were observed, and researchers found that non-Hispanic white youth recorded less accelerometer counts per minute than non-Hispanic Black and Mexican American youth.[22] It is clear from the existing literature that total PA and amount of PA at higher intensities is associated with these characteristics. It is unclear, however, how these characteristics may play a role in influencing PA patterns during the school day and week.

Participant sex is also an important characteristic that may play an important role in the PA of youth.[20] Participation in habitual PA is important for both males and females, and sex differences in PA patterns have been reported in previous studies examining physical activity during specific times of the day and overall physical activity.[20] Mota et al., 2003, found that when examining sex differences in within-day PA, girls showed a higher percentage of time engaged in moderate-to-vigorous PA (MVPA) during the morning and early afternoon periods, while boys engaged in MVPA at a higher percentage during the late afternoon and evening periods.[19] Additionally, Trost et al., 2001 found that for children in grades 1–6, boys were more active than girls. In this same study the authors found that for MVPA, the sex difference ranged from 8.4% in grades 10–12 to 18.9% in grades 1–3, and the average sex difference for MVPA was 11%, with boys accumulating more MVPA than girls.[20] There is limited evidence, however, that differences in PA patterns exist between boys and girls.

Girls and children in general who are located in underserved and low income areas may be at a further disadvantage to be physically active as previous literature suggests that this demographic has less access to safe and appropriate spaces for indoor and outdoor activity and

less access to community programs like after-school programs and youth sports.[25,26] Lower access to safe and quality opportunities to be active in underserved and low-income areas results in a higher percentage of youth engaging in sedentary activities like playing video games, watching television, excessive phone use and other computer activities.[25] This decline in PA as girls age, coupled with the associated increase in body mass index (BMI) and adiposity and the barriers that exist to PA in low income areas, makes the promotion of healthy PA behaviors in low income, racially diverse girls of utmost concern.[10,11,12,13,14,16,17] Further characterization of temporal patterns and the factors that may be related to them during the school day may not only be useful for general PA promotion, but also for developing new PA interventions targeted at specific times during the day, with the end goal of improving the overall health and PA behavior of our youth. Given these gaps in the literature, the aims of this study were:

***Specific Aims/Hypotheses***

**Aim 1.** To compare average MVPA min/hr across different time-points during the day, "before-school time", "during-school time", after-school time", and "evening", to search for possible associations and patterns in PA across these time periods in a group of adolescent girls, a high percentage of whom are Black, who come from a predominantly low-income background.

**Hypothesis 1a.** Average MVPA min/hr during "before-school time" will have a significant and positive association to average MVPA min/hr in "during-school time". (Evidence for Synergy)

**Hypothesis 1b.** Average MVPA min/hr occurring in "during-school time" will have a significant and negative association to average MVPA min/hr in "after-school time". (Evidence for Compensation...suppressed PA time during the school day leads to higher MVPA after school)

**Hypothesis 1c.** Average MVPA min/hr during "after-school time" will have a significant and negative association to average MVPA min/hr during "evening time". (Evidence for Compensation).

**Aim 2.** To examine associations between average MVPA min/hr achieved in each individual time-period and participant factors of interest.

**Hypothesis 2:** There will be significant associations between MVPA min/hr achieved in each time period (before school, during school, afterschool, and evening) and participant factors such as age, race/ethnicity, cardiorespiratory fitness, and percent body fat.

## METHODS

In order to examine the temporal patterns of girls' PA during the school day, data collected from the Girls on the Move (GOTM) PA intervention study was used. This study is a secondary analysis of the GOTM group randomized control trial and is a cross-sectional analysis of only data from the *baseline* time-point. Only baseline data was used for this study as we were interested in habitual physical activity rather than the effects of the GOTM intervention. More detailed information regarding the GOTM intervention is published in previous studies but not relevant to the current investigation.[8,15]

### *Participants*

GOTM examined girls 10–14 years old in $5^{th}$–$8^{th}$ grade (N=1519). Recruitment took place in September of 2012, 2013 and 2014, and girls were recruited from 24 racially diverse, urban schools in low SES areas in the Midwestern U.S. These schools were matched in pairs based on their similarity in academics (grades), enrollment/school size, racial/ethnic composition, and percent of girls eligible to receive free/reduced price lunch (indicator of socioeconomic status). Schools were randomized to either control (N=12) or treatment (N=12).

Schools were included in GOTM if they were located in an urban community setting, had enrollment greater than 100 girls in each school or more than double the number of girls needed for the study site (n=50 per school) in any combination of 5th, 6th, 7th, and/or 8th-grade, and had a student body comprised of 50% or higher minority versus non-minority race or ethnicity. Schools were excluded from GOTM if administrators were not interested in participating in the intervention, did not agree to random assignment, or could not guarantee their availability at 9-month post-intervention follow-up. Individual girls participating in GOTM had to be in 5th, 6th, or 7th-grade (ages 9–14), available and willing to participate in a physical activity club (PA Club) 3 days per week for 17 weeks, available for follow-up, willing to agree to random assignment, and able to understand and speak English. Girls were excluded if they were currently participating in or planned to be participating in school or community sports or other organized PA that involved MVPA and required participation 3 or more days per week after school during every season of the school year. After the randomization was complete, there were 766 girls in the control group, and 753 girls in the treatment group. The main outcome of interest for the GOTM study was minutes of moderate-to-vigorous PA (MVPA). [8,15]

***Data Collection and PA Measurement***

The full GOTM data set (N=1519) was used to examine temporal patterns of girls' PA during the baseline time point to examine habitual PA behavior without the influence of the PA intervention. Data were collected in the fall for the baseline timepoint. Minutes of MVPA were measured via ActiGraph GT3X+ accelerometers worn on an elastic belt at the right hip for 7 consecutive days, including 5 weekdays and 2 weekend days. However, only weekdays (school days) were used in the analysis for this study. Monitors were set to start collecting and storing data beginning at 5:00 A.M. on the day after distribution to girls. Data were collected in raw

mode at 30 hertz and re-integrated to 15-second epochs, processed using Evenson cut-points (using counts from the vertical axis only). [8,15]

The days in each week of data collection were split into "before-school time", "during-school time", "after-school time", and "evening time." Before-school time was characterized as the one-hour period before school started, from 7am to 8am. During-school time was characterized as the 7-hour period during the day, from 8am to 3pm. After-school time was characterized as the 3-hour period from 3pm to 6pm and evening time was characterized as the 3-hour period from 6pm to 9pm.[15] Average minutes of MVPA/hr were calculated by taking the total minutes of MVPA for a specific time period and dividing by the number of hours in that time period (ex. Minutes of MVPA during school time divided by 7 hours during that time period). Other variables of interest included cardiorespiratory fitness, assessed using the using the Progressive Aerobic CV Endurance Run (PACER) 15m or 20m shuttle run [24], and percent body fat measured to the nearest 0.1% using a foot-to-foot bioelectric impedance scale (Tanita Corporation, Tokyo, Japan). Demographics information such as age and race/ethnicity were collected face-to-face at baseline by trained GOTM research team members.[15] More information regarding assessment of fitness and percent body fat can be found in Robbins et al. 2015.

***Missing Data and Statistical Analysis***

As with the primary analysis of outcomes in the GOTM study, missing data were imputed.[15] When girls did not complete 60 minutes of accelerometer wear time, data for that hour were considered missing and then imputed. Average MVPA for each week was calculated from 100 imputed data sets based on 14 hours for each weekday and 10 hours for each weekend day. This method is comparable to imputation procedures from previous research involving adolescent girls.[18] Out of 90 potential hours for the week, the mean percentage of missing hours

was 13.3%. If data during a time block of one hour were incomplete, the entire hour was considered missing.

All statistical tests were completed using R studio analysis software. Additionally, a post hoc power analysis was performed using G Power software to calculate this study's predicted power. Estimated effect size of 0.48 was calculated using accelerometry-based in-school and out-of-school MVPA data in girls from a previous study.[27] Using this effect size of 0.48, an alpha level of 0.05, and the sample size of n=1519, the power analysis revealed 99% power to avoid type II error (Supplementary Table S.2).

To evaluate Aim 1, Kendell's tau coefficients were computed to compare average MVPA min/hr across all time periods (before-school, during-school, after-school, and evening). To evaluate Aim 2, linear regressions were conducted to examine relationships between each of the four time periods and participant characteristics.

## RESULTS

### *Aim 1*

Overall average MVPA min/hr was highest during the before- school period (6.11 ± 2.92 min/hr). It dropped during school-time hours to 2.98 ± 1.2 min/hr, and then rose again during the afterschool and evening periods (5.27 ± 2.11 min/hr, 4.84 ± 2.0 min/hr, respectively) Furthermore, average MVPA/hr across all five weekdays at baseline and across all four time-points was 3.18 ± 3.81 min/hr. Average MVPA minutes per day was 44.5 ± 18.47 min/day. Overall, 277 (18%) girls achieved an average MVPA minutes per day greater than or equal to daily PA recommendations of 60 minutes per day.

Kendall's tau revealed significant correlations ($p<0.001$) for average MVPA min/hr which were found between all four time periods, with the strongest correlation occurring

between after-school and evening time periods (f=0.563, p<0.001), and the weakest correlation occurring between before-school and evening time periods (f = 0.177, p<0.001) (Table 3.1).

**Table 3.1: Kendell's tau across all four time periods**

| | Before School | During School | After school | Evening |
|---|---|---|---|---|
| **Before School** | _ | 0.284* | 0.401* | 0.177* |
| **During school** | 0.284* | _ | 0.366* | 0.389* |
| **After school** | 0.401* | 0.366* | _ | 0.563* |
| **Evening** | 0.177* | 0.389* | 0.563* | _ |

*significant, p <0.001

***Aim 2***

Linear regressions revealed that before school, age was significantly and positively related to average MVPA min/hr (p<0.001) (Table 3.2). During school, age (negative association) and being Black were significant predictors of higher MVPA min/hr (p<0.001, 0.001, respectively) (Table 3.3). After school, being Black or Hispanic were significant predictors of higher average MVPA min/hr (p<0.001 for both) (Table 3.4). Finally, in the evening, Black was positively associate with higher average MVPA min/hr (p<0.001) and age was negatively associated with average MVPA min/hr (p<0.001) (Table 3.5). Estimated $VO_2$ max and body fat percentage were not found to be significantly associated with average MVPA min/hr during any time.

**Table 3.2: Associations of average minutes of MVPA min/hr during <u>before-school</u> time with participant characteristics**

| | Estimate | SE | t | p-value |
|---|---|---|---|---|
| **Intercept** | 5.03 | 3.49 | 1.44 | 0.15 |
| **Estimated VO2max** | -0.08 | 0.06 | -1.38 | 0.17 |
| **Baseline Body Fat** | -0.04 | 0.03 | -1.47 | 0.14 |
| **Hispanic (YES)** | 0.23 | 0.23 | 0.99 | 0.32 |
| **Black (YES)** | 0.20 | 0.16 | 1.29 | 0.20 |
| **Age** | 0.04 | 0.01 | 5.50 | <0.001*** |

***significant, p<0.001

**Table 3.3: Associations of average minutes of MVPA min/hr <u>during-school</u> time and participant characteristics**

| | Estimate | SE | t | p-value |
|---|---|---|---|---|
| **Intercept** | 4.78 | 1.43 | 3.35 | <0.001*** |
| **Estimated VO2max** | -0.01 | 0.02 | -0.53 | 0.59 |
| **Baseline Body Fat** | -0.01 | 0.01 | -1.01 | 0.31 |
| **Hispanic (YES)** | 0.18 | 0.09 | 1.95 | 0.05 |
| **Black (YES)** | 0.42 | 0.06 | 6.42 | <0.001*** |
| **Age** | -0.01 | 0.003 | -3.14 | 0.001* |

*significant, p<0.05
***significant, p<0.001

**Table 3.4: Associations of average minutes of MVPA min/hr after-school time and participant characteristics**

| | Estimate | SE | t | p-value |
|---|---|---|---|---|
| **Intercept** | 5.30 | 2.52 | 2.12 | 0.04* |
| **Estimated VO2max** | -0.02 | 0.04 | -0.59 | 0.56 |
| **Baseline Body Fat** | -0.03 | 0.02 | -1.30 | 0.19 |
| **Hispanic (YES)** | 0.77 | 0.16 | 4.700 | <0.001*** |
| **Black (YES)** | 0.69 | 0.11 | 5.98 | <0.001*** |
| **Age** | 0.01 | 0.004 | 1.79 | 0.07 |

*significant, p<0.05
***significant, p<0.001

**Table 3.5: Regression Analysis comparing average minutes MVPA min/hr in the evening and participant characteristics**

| | Estimate | SE | t | p-value |
|---|---|---|---|---|
| **Intercept** | 5.99 | 2.37 | 2.53 | 0.01* |
| **Estimated VO2max** | 0.03 | 0.04 | 0.85 | 0.40 |
| **Baseline Body Fat** | -0.01 | 0.02 | -0.54 | 0.59 |
| **Hispanic (YES)** | -0.03 | 0.15 | -0.21 | 0.83 |
| **Black (YES)** | 0.48 | 0.11 | 4.40 | p<0.001*** |
| **Age** | -0.02 | 0.004 | -3.64 | p<0.001*** |

*significant, p<0.05
**significant, p<0.01

## DISCUSSION

The results of this study show that even though previous literature has shown PA behavior to be highly variable, average MVPA min/hr during specific time periods throughout the day is related. Although previous literature has examined PA at different time periods during the day,

very few have aimed to examine patterns and relationships which exist between those time periods. It must be noted that MVPA/hr achieved by girls in this sample is low. Only 18% of this sample of girls achieved the recommended 60 minutes of MVPA/day. According to Merlo and colleagues, nationally, only 24% of youth ages 6–17 are meeting the PA guidelines.[41] Our data is in accordance with previous literature which suggests that girls and racial/ethnic minorities in low-income areas are at higher risk for low PA. [10,11,12,13,14,16,17,19,20,22,41,43]

Results suggest evidence for PA compensation. The overall average MVPA min/hr rose and fell throughout the day with girls exhibiting the highest MVPA min/hr before school and after school. The lowest average MVPA min/hr occurred during school and in the evening. These results are similar to previous findings by Mota et al., 2003 who also found that girls participated in more MVPA during the morning and early evening periods, which in the case of the current study, could be explained by girls actively commuting to school. This type of fluctuation in PA behavior indicates that girls may compensate and follow a period of higher average MVPA min/hr with a period of lower MVPA min/hr and vice versa. These results are similar to results found by Fremeaux et al., 2011 and Gidlow et al., 2008 who also found that girls compensate so that more activity at one time is met with less activity at another. It is possible, however, that this evidence is not actually indicative of habitual PA patterns, but the strong influence that the school day has on PA in other time-periods.

Significant, positive correlations were also shown to exist between all four time periods, and the average MVPA min/hr achieved during one time-period for girls (high or low) was similar to the MVPA min/hr achieved in other time-periods. Interestingly and in contradiction to the above findings, it is possible that these results show evidence for PA synergy, as consistency in PA levels over different time periods is indicative of synergy. However, correlations were relatively low and

most likely found to be significant due to the large sample size in this study. Findings suggesting compensation and possibly synergy in this study highlight the possibility that these terms may not be the best way to describe youth PA patterns. Compensation seems to happen often as the result of the school day schedule, while synergy is seen when highly active or less active girls maintain a consistent level of PA over time. Evidence for both patterns across the full body of literature suggests that youth may not do one or the other but are both compensatory and synergistic at different times depending on individual characteristics, daily school schedule, and home life.

In addition, results indicate that average MVPA min/hr during these time periods may be related to specific individual participant factors. Previous literature has shown that participant characteristics such as age, CV fitness, race/ethnicity, and body fat percentage are associated with overall PA behavior, but very few researchers have considered how these characteristics may be related to PA during certain times of the day. Although hypothesis 2—that all participant characteristics would be significantly related to average MVPA min/hr at each time point—was rejected, results from this study show that certain characteristics, specifically age and race/ethnicity, may be indicative of average MVPA min/hr during certain times of the day. Older girls were found to be more active before school, and younger girls were found to be more active during school and in the evening. It is possible that older girls in this sample were given more freedom by parents to actively commute to and from school, explaining higher average MVPA min/hr during these time periods. Younger girls may have been given more opportunities to be active during the school period (more breaks and more active classes) resulting in a higher average MVPA min/hr during this time.

Being Black was a predictor for higher-than-average MVPA min/hr during school, after school, and in the evening. Being Hispanic was a predictor for higher-than-average MVPA min/hr

after school. Although no previous literature examines racial disparities in MVPA by race for specific time periods, Gortmaker et al., 2012, found that non-Hispanic Black youth were more active that non-Hispanic white youth, but over time there was overall decrease in MVPA accelerometer counts for non-Hispanic Blacks and Mexican Americans that non-Hispanic whites did not experience. More information regarding racial disparities and the influence of other participant characteristics on PA during different times of the day could help researchers and health promoters focus their attempts to increase PA on girls who most need it during targeted time periods where we know girls are more/less active.

Furthermore, it seems that the after-school period is an extremely important part of the day, a finding that has also been identified by previous literature and explored through the implementation of after-school PA programs and interventions.[33,34,35,36,37,38,42,43] Past after-school interventions have showed promising results, but very few were successful at getting youth to meet the 30 minutes of MVPA during the after-school period as recommended by the National Afterschool Association's Healthy Eating and Physical Activity Standards (HEPA).[39,40] The current study showed that the after-school period was significantly correlated with each of the other three time periods, particularly with MPVA/hr during the evening. This, coupled with the fact that it is a period immediately following the least active time (school day), suggests that both the school day and after-school period should be a continued target for future promotion of physical activity using interventions and other novel strategies. Offering after-school programs and other after-school activities for youth in addition to more opportunities to be active during the school day may help to increase PA immediately following school time, increase overall PA, and lead to better overall health and fitness.

### *Strengths and Limitations*

Limitations of this study included a sample of only girls, only one week of analyzed data, and examination of MPVA on weekdays only. Furthermore, very little information regarding how girls commuted to and from school, or what active events, other than PE, existed during the school day were obtained. In this study, an examination of only girls' PA patterns was conducted because girls have been identified in previous research as being at higher risk for sedentary activity compared to boys. Only one week of data, at baseline, were examined to avoid the influence of the intervention with the hopes of capturing true, habitual PA patterns. Regardless, future research should address these limitations by including boys to further our knowledge of PA patterns for all youth, by including examination of MVPA over longer periods of time as well as during weekends, and finally, by examining how active commutes to and from school may have an influence on temporal patterns of PA in youth.

Despite these limitations, the current study also has many strengths. These strengths include a large sample size of 1,519 girls that were high percentage racial/ethnic minorities. The current study also included a thorough examination of the relationships between four separate time periods during the school day, as well as analysis of several important participant characteristics that have been previously identified as influences overall PA behavior.

### *Conclusion*

In conclusion, the characterization of temporal patterns of PA in girls is still unclear. Similar to previous research, it seems that youth PA patterns are highly variable. In general, average MVPA rose and fell in a compensatory manner throughout the school day, although it is not clear if this is a habitual pattern or due to the structure schedule of the school day in the United States. Age was found to be the most important predictor for MVPA during the day,

showing that older girls were more active in the morning, after school, and evening, while younger girls were more active during school. Although Kendall's tau correlations were significant but relatively small, it seems that PA during the after-school period is especially important and could influence other time periods during the day. More research should be conducted during the after-school period to examine how it can be used to promote PA and increase PA during other time periods of the day and overall. More research is needed on this topic to truly characterize existing temporal patterns of PA in youth. Understanding when youth are normally active as well how PA during one time may influence PA in another could lend valuable information to both health promoters and researchers to increase overall PA and eventually improve the overall health and fitness of our youth.

**Table S.2: Power Analysis Table for Different Effect Sizes**

| Effect Size | Predicted Power |
|---|---|
| 0.2 | 99% |
| 0.4 | 99% |
| 0.6 | 99% |
| 0.8 | 99% |

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## Chapter 4: Manuscript 3

# Comparing After-School Physical Activity Patterns Prior to and During an After-School Program in the Girls On the Move Intervention

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**ABSTRACT**

**Introduction:** The average American school day consists of several time periods that all contribute, in some way, to overall youth physical activity (PA). With many schools decreasing in-school physical activity classes, we must look to other time periods to help children increase and maintain an acceptable level of PA. A closer examination of after-school time could lead to a better understanding of how this important period contributes to overall PA. **Purpose:** The purpose of this study was to examine PA during the Girls on the Move (GOTM) after-school program to identify patterns and predictive participant characteristics of PA behavior. **Methods:** Examination of the after-school period was accomplished by using data from the GOTM after-school program. Data for 119 girls aged 9–14 in 5 intervention schools were examined to compare moderate to vigorous PA (MVPA) during the after-school period at baseline of GOTM to MVPA achieved during the after-school PA program. Participant characteristics (i.e., body fat percentage, cardiorespiratory fitness, maturity status, age, and race/ethnicity) were also examined to see which were associated with a significant increase in MVPA from baseline to the after-school program. **Results:** Girls were on average 11.9 years ± 0.97 and were 64.7% Black, 11.9% Hispanic or Latino, and 23.4% white/mixed/other. Every minute increase in average afterschool MVPA min/hr at baseline was associated with a corresponding additional 3.90 minutes of MVPA min/hr during the PA club when controlling for school attended and overall baseline MVPA min/hr (ß=3.90 ± 0.31, $p<0.001$). Girls who had higher overall MVPA min/hr at baseline were found to be significantly more active during PA club (ß=0.20 ± 0.03, $p<0.001$). No significant associations were found between average MVPA min/hr achieved during the after-school PA club and any participant factors of interest. There was evidence to suggest that earlier maturers were less active during the after-school PA club ($p=0.05$). **Conclusions:** No major

factors, aside from overall MVPA, were found to be associated with MVPA during the after-school club. This finding is not in line with previous research, which suggests that body fat percentage, cardiovascular fitness, age, and race/ethnicity are factors in determining PA behavior. Maturity status, although not found to be significant did have an association with MVPA during the after-school club approaching significance ($p=0.05$) More research is needed to examine the relationship of maturity status and other participant characteristics that may be associated specifically with the after-school period as well as other times during the day.

## INTRODUCTION

Regular participation in physical activity is important for youth for a variety of reasons. For example, habitual physical activity (PA) can lead to a reduction in the risk for certain diseases and better mental health through improvements to sleep and energy levels.[1,2,3,4] Due to the fact that most youth spend the majority of their weekday time in a school setting, their patterns of PA are undoubtedly influenced by scheduled events (active or inactive) during the school day. Given that school attendance is mandated, schools are an ideal setting to promote PA and offer potential opportunities before, during, and after school.[17] It is, therefore, important to evaluate PA during the school day and in time periods surrounding the school day in order to better understand how much and how often youth are being physically active in the face of a largely sedentary school schedule.

Much of the previous literature examining school day PA focuses on overall MVPA achieved. There are other aspects of PA that are important but less examined in the current literature. One of these aspects is the concept of temporal patterns of PA, a concept that suggests that individuals follow specific patterns in PA behavior over the course of a day, week, month, season, or other specified time period. A better understanding of these patterns in youth during the school day or the after-school period may be valuable in characterizing how much PA youth are obtaining. Understanding which variables affect their PA during these time periods and identifying which promotion strategies are effective might be useful in helping youth be more active. Previous literature shows that the after-school time period is important for examining and targeting promotion of PA. According to the CDC, less than one-quarter (24%) of children 6 to 17 years of age participate in 60 minutes of physical activity every day. [38] Accumulated school day PA has been found to be lower, on average, than out-of-school PA, but less than 50% of kids

are compensating for low PA during school with high PA afterschool [49]. This highlights that promotion of PA during the school day is important, but also that the after-school period represents a quality time to try to help achieve the recommended 60 minutes of PA despite a restrictive school day schedule. Whether this overall lack of PA is primarily due to habitual patterns or barriers to physical activity (e.g. unsafe neighborhoods and/or no access to sports equipment, parks, or playgrounds) is unknown.

It is also important to identify and examine certain groups of individuals who may be at higher risk for low PA levels, and previous studies have already shown sex differences in the amount of PA obtained during the day. Mota et al., 2003, found that when examining sex differences in within-day PA, girls showed a higher percentage of time engaged in MVPA during the morning and early afternoon periods, while boys engaged in MVPA at a higher percentage during the late afternoon and evening periods, with boys obtaining significantly more minutes of MVPA over the course of the day.[21] Similarly, Trost et al. found that boys in grades 4–12 accumulated higher average minutes of MVPA per day than girls.[22] Further evidence from previous studies examining the PA behavior of only girls, however, reveals concerning results showing that girls' PA declines as they age, and by the time they reach the 9$^{th}$ grade, only 22% meet the recommendations for PA.[15] Additionally, by the 9$^{th}$ grade, 28% of girls are already characterized as overweight or obese.[8,9] This coupling of reduced PA with increased adiposity highlights a strong need for new PA promotion strategies to be established for girls. [10,11,12,13,14,50,51,52,53] The after-school period presents an excellent opportunity for health and PA promoters to help girls meet recommended PA guidelines, develop health behaviors, and ultimately help them grow into healthy adults and lower their risk for adverse health outcomes.[18,19,20] Unlike the typical, sedentary structure and schedule of the school day, after-

school time allows researchers and PA promoters more control over the PA of youth. There are a variety of ways in which youth are physically active after school, whether it is through participation in youth sports, unorganized play with peers, or school and/or community-based after-school programs. Unfortunately, previous research has shown an increase in sedentary time during the afterschool period as youth age. Santiago-Rodriquez et al. 2022, observed that adolescents (15.3 years ±1.7), on average, accumulated 8.4 min/hour more sedentary time each day compared to children (9.2 years ±2.1) during after-school period.[48] Closer examination of after-school PA and PA during a PA-based after-school program may give insight and valuable information into 1) how school-day PA may affect after-school PA, 2) how much physical activity youth are obtaining during this crucial time period, and 3) what additional factors may be influencing after-school physical activity.[5] Better characterization of temporal patterns and identification of important times of the day, like the after-school period, which contribute to overall PA is an important step in increasing the overall PA of youth. But it may also be important to consider individual characteristics such as body fat percentage, cardiorespiratory fitness (CRF), race/ethnicity, and age, which have been examined in previous literature, and may be important in shaping temporal patterns of PA across the school day/week.[23,24]

Race/ethnicity may also be a factor influencing when youth are active and how much PA they are accumulating at different time points during the day and week. Barriers, such as limited access to safe spaces in which to play and be active, and minimal availability of equipment, have been found to affect participation in PA for low socioeconomic status (SES) families and racial and ethnic minorities. and may greatly influence temporal patterns of PA for Black or Hispanic children and adolescents.[31,32,33] A study by Anderson et al. suggested that race/ethnicity play a role in the accumulation of PA and showed that Black and Hispanic children have a greater

likelihood of low active playtime and high screen time.[24] After-school programs are one means to examine PA patterns in low SES areas and racial/ethnic minority groups, particularly considering that Hynes et al. found that Black children and adolescents are two times as likely to attend an after-school program than their white peers.[30] It is, therefore, important to examine temporal patterns of PA between days during an after-school program and non-program days in an underserved population. By exploring different promotion strategies and after-school programs, researchers could examine if those participants who were most active at baseline are also most active at the end of the intervention, and which individuals respond more positively to a particular intervention.

Examination of PA in girls during the after-school time period, with respect to this study, will be accomplished using data from the Girls on the Move (GOTM) study. This 17-week, after-school intervention targeted middle school aged girls in urban, low-income areas with a high percentage of Black girls (52.3%).[27] The intervention aimed to increase overall PA behavior by incorporating the Health Promotion Model (HPM) and the Self-Determination Theory (SDT). Although the GOTM intervention did not accomplish its original goal of increasing overall PA, a closer look into PA behavior during the after-school club may provide valuable information regarding PA during after school programs for future research.[15] An examination of girls in this demographic is especially important as 1) those in low-income areas may have less access to safe and high-quality opportunities to be active and 2) there has been little examination of temporal patterns in this demographic in existing literature, and it is unknown how their temporal patterns of PA may differ.[26] Thus, given these gaps in knowledge, the aims of this study were:

***Specific Aims & Hypotheses:***

**Aim 1.** To examine the extent of the difference between average MVPA min/hr achieved during the GOTM after-school PA club and average MVPA min/hr achieved in the after-school time-period at baseline of the GOTM intervention.

**Hypothesis 1.** Average MVPA min/hr during the after-school PA club will be significantly higher than that achieved during the after-school period at baseline.

**Aim 2.** To identify differences in average MVPA min/hr during the after-school PA club between schools while controlling for baseline after-school MVPA min/hr

**Hypothesis 2.** There will be no differences between schools in average MVPA min/hr achieved during the after-school PA club.

**Aim 3.** To identify individual participant factors that may be associated with significant increases in MVPA min/hr during after-school time from baseline to the after-school PA club while controlling for school and overall, baseline MVPA.

**Hypothesis 3.** Body fat percentage (negative association), cardiorespiratory fitness (positive association), maturity status (negative association), age (negative association), and race/ethnicity will all be associated with a significant increase in average MVPA min/hr during the after-school club.

**METHODS**

***GOTM Intervention and its Participants***

The GOTM group randomized controlled trial included a total of 24 racially diverse urban (inner-city) schools (12 intervention:12 control) and examined girls (n=1519, 766 control, 753 intervention) 10–14 years old in the Midwestern U.S., at the beginning and end of each of three academic years (2012–2015). Inclusion criteria for schools in GOTM were 1) if they were

located in an urban community setting, 2) if they had enrollment greater than 100 girls in each school or more than double the number of girls needed for the study site (n = 50 per school) in any combination of 5th, 6th, 7th, and/or 8th-grade, and 3) if they had a student body comprised of 50% or higher minority versus non-minority race or ethnicity. Exclusion from GOTM occurred if 1) administrators were not interested in participating in the intervention, 2) schools did not agree to random assignment, or 3) schools could not guarantee their availability at 9-month post-intervention follow-up.[15] Inclusion criteria for individual girls participating in GOTM were that girls had to be in 5th, 6th, or 7th-grade (ages 9–14), were 1) available and willing to participate in PA Club 3 days per week for 17 weeks, 2) were available for follow-up, 3) agreed to random assignment, and 4) were able to understand and speak English. Girls were excluded if they were currently participating in or planned to be participating in school or community sports or other organized PAs that involved MVPA and required participation 3 or more days per week. after school during every season of the school year.[15,16] The GOTM after-school PA club was offered to girls in the intervention group three days a week (Tuesday through Thursday) for the full 17-week study duration (Sept–Jan) and was run by trained PA club coaches and managers.[16] Club was always held on these days, with the exception of scheduled school breaks or cancellations due to weather. The PA club was 90 minutes long and designed to include 10 minutes for a healthy snack and water, a 5-minute warm-up activity, 60 minutes of moderate to vigorous physical activity (MVPA), and a 5-minute cool down activity. The main objective for this PA club was to engage the girls in MVPA for at least 50% of the 60-minute MVPA period.[16]

The GOTM intervention itself was 17 weeks long and comprised of three main components which included **1)** two face-to-face motivational counseling sessions facilitated by the school nurse and tailored to each individual (occurred at baseline and 17 weeks), **2)** an

interactive, internet-based session where each participant received motivational and feedback messages, once again tailored to each individual (occurred at 9 weeks), and **3)** a group level component consisting of a 90-minute after-school PA club which was led by PA instructors (e.g., individuals from community; teachers, including physical education (PE); and sports team coaches). More detailed information and explanation of the GOTM intervention study, its methods, and its results are noted in previous publications.[8,15,16] This study will focus on MVPA data obtained from the 90-minute PA club. Therefore, in this cross-sectional study we will examine a subset of girls (n=119, aged 10–14 years) from five of the twelve intervention schools who were randomly selected to have MVPA measured during the PA club. These five schools were included because data for the other seven other schools did not have student names or ID numbers matched with the participants, making it impossible to compare baseline MVPA to MVPA during the after-school club.

***Data Collection and PA assessment***

At baseline, overall minutes of MVPA were measured via ActiGraph GT3X+ accelerometers worn on an elastic belt at the right hip for 7 consecutive days, including 5 weekdays and 2 weekend days. However, only weekdays (school days) were used in the analysis for this study. Monitors were set to start collecting and storing data beginning at 5:00 A.M. on the day after distribution to girls. Data were collected in raw mode at 30 hertz and re-integrated to 15-second epochs, processed using Evenson cut-points (using counts from the vertical axis only), and configured into average accelerometer counts of MVPA/hr.[15,16] The days in each week of data collection were split into "before-school time", "during- school time", "after-school time", and "evening time." Before-school time was characterized as the one-hour period before school started, from 7am to 8am. During-school time was characterized as the 7-hour period

during the day, from 8am to 3pm. After-school time was characterized as the 3-hour period from 3pm to 6pm and evening time was characterized as the 3-hour period from 6pm to 9pm.

To evaluate MVPA during the PA club time, five girls were randomly chosen from each intervention school every other week to wear an ActiGraph GT3X+.[16,39] Monitors were secured by elastic waist belts worn at the right hip for the duration of one to three after-school program days over the course of one week. Data were collected in raw mode at 30 hertz and re-integrated to 15-second epochs, processed using Evenson cut-points, and configured into average accelerometer counts of MVPA min/hr [8,15,16] Average MVPA min/hr from the same sub-sample of 119 girls was compared between the baseline of the GOTM intervention and PA club time. In addition to MVPA, information regarding cardiorespiratory fitness, body fat percentage, age, and race/ethnicity were collected at baseline, prior to initiation of the intervention. Cardiorespiratory fitness was measured using the Progressive Aerobic CV Endurance Run (PACER) 15m and 20m shuttle run.[29] Percent body fat was measured to the nearest 0.1% using a foot-to-foot bioelectric impedance scale (Tanita Corporation, Tokyo, Japan). Maturity status was assessed using the Pubertal Development Scale, where girls rated themselves compared to other girls of similar age, on body hair and breast development. [40,41] Finally, demographics information such as age and race/ethnicity were collected face-to-face at baseline by trained GOTM research team members.[15]

***Data Reduction and Analysis***

As in the analysis of the primary outcomes paper of GOTM study, baseline data were imputed when missing.[15] Data for those who did not complete 60 minutes of accelerometer wear time were considered missing and then imputed for that hour. Average MVPA for each week was calculated from 100 imputed data sets based on 14 hours for each weekday and 10 hours for

each weekend day. This imputation method is comparable with procedures used in previous research involving adolescent girls.[28] The mean percentage of missing hours was 13.3% out of the 90 potential hours for the week. For the afterschool PA club, only girls who had at least one full club day of wear time (90 minutes) were included in the analysis. Some girls recorded many more days, especially if there were not many girls who attended each week at their school. Average MVPA min/hr during the afterschool PA club was calculated for each girl who participated.

To evaluate Aim 1, mixed effects regressions were used to compare the difference in average MVPA min/hr during the after-school program and baseline after-school time while controlling for school and total baseline MVPA min/hr . To evaluate Aim 2, Welches ANOVA (to avoid violating homogeneity of variance and better account for baseline differences between schools) was used to examine change in average MVPA min/hr from baseline after-school time to the GOTM after-school club among participating schools. Finally, to evaluate Aim 3, linear regression was completed to examine associations between average MVPA min/hr during after-school time and the after-school PA club and certain participant factors (i.e., age, % Body Fat, CV fitness, maturity statues, race/ethnicity (reference group being non-Hispanic whites), baseline MVPA) (The intraclass correlation coefficient for variability within schools was low (always <0.20), indicating a multilevel model (observations nested within schools) is not necessary).[54]

Analyses for all aims were completed using R studio software. Additionally, a power analysis to compare two dependent means (matched pairs) was completed using G Power software to predict statistical power. An effect size of 0.41 was calculated using accelerometer-based MVPA data from previous studies examining normal after-school time and MVPA data

during an after-school PA program.[16,34] Using an alpha level of 0.05, an effect size of 0.41, and the sample of n=93, the two-tailed power analysis revealed 97% power to avoid type II error. Power analyses were also conducted for varying effect sizes. The results of these analyses are listed in Supplementary Table S.3.

## RESULTS

Data for 119 girls from five intervention schools were used to analyze PA measured during the PA club. On average, girls participating in the PA club attended an average of 41% of club sessions. These girls had a mean age of 11.9 years ± 0.97, were 64.7% Black, 11.9% Hispanic or Latino, and 23.4% white/mixed/other (Table 4.1). Participant demographics and other important characteristics are listed in Table 4.1.

**Table 4.1: Descriptive Characteristics of GOTM After School Club Participants by School**

| | School A (N=20) | School B (N=25) | School C (N=28) | School D (N=27) | School E (N=19) | Overall (N=119) |
|---|---|---|---|---|---|---|
| **Black** | | | | | | |
| No | 3 (15.0%) | 8 (32.0%) | 10 (35.7%) | 17 (63.0%) | 4 (21.1%) | 42 (35.3%) |
| Yes | 17 (85.0%) | 17 (68.0%) | 18 (64.3%) | 10 (37.0%) | 15 (78.9%) | 77 (64.7%) |
| **Hispanic** | | | | | | |
| No | 18 (90.0%) | 23 (92.0%) | 27 (96.4%) | 24 (88.9%) | 13 (68.4%) | 105 (88.2%) |
| Yes | 2 (10.0%) | 2 (8.0%) | 1 (3.6%) | 3 (11.1%) | 6 (31.6%) | 14 (11.8%) |
| **Pubertal Stage** | | | | | | |
| Early-Mid (later maturer) | 10 (50.0%) | 18 (72.0%) | 17 (60.7%) | 25 (92.6%) | 9 (47.4%) | 79 (66.4%) |
| Late (earlier maturer) | 10 (50.0%) | 7 (28.0%) | 11 (39.3%) | 2 (7.4%) | 10 (52.6%) | 40 (33.6%) |
| **Age (years)** | 13.1 (0.91) | 12.0 (0.57) | 11.9 (0.69) | 10.9 (0.66) | 12 (0.68) | 11.9 (0.97) |
| **Average After School Club Days attended (days)** | 1.55 (0.69) | 1.76 (0.71) | 1.61 (0.67) | 1.74 (0.81) | 1.52 (0.59) | 1.64 (0.71) |

**Table 4.1 (cont'd)**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Baseline VO2 (ml/kg/min)** | 39.5 (4.1) | 38.0 (4.7) | 38.6 (5.2) | 40.2 (4.0) | 36.8 (6.0) | 38.7 (4.9) |
| **Baseline BMI z-score** | 0.4 (1.0) | 1.0 (0.9) | 0.9 (1.1) | 0.7 (1.1) | 1.2 (1.1) | 0.8 (1.0) |
| **Baseline Body Fat (%)** | 25.4 (8.1) | 29.8 (8.9) | 28.3 (10.5) | 26.6 (8.4) | 31.7 (10.8) | 28.3 (9.5) |
| **Before School MVPA min/hr** | 8.5 (7.1) | 6.1 (3.0) | 4.6 (2.2) | 6.0 (1.9) | 5.3 (3.6) | 6.0 (3.9) |
| **During School MVPA min/hr** | 3.2 (1.4) | 2.8 (1.4) | 3.6 (1.2) | 3.5 (1.2) | 2.3 (0.8) | 3.2 (1.3) |
| **After-School MVPA min/hr** | 7.3 (2.8) | 4.6 (1.8) | 4.8 (2.8) | 5.1 (1.7) | 5.5 (2.1) | 5.3 (2.4) |
| **Evening MVPA min/hr min/hr** | 6.1 (2.4) | 5.6 (1.6) | 4.7 (1.4) | 5.3 (1.9) | 3.7 (1.5) | 5.1 (1.9) |
| **Total Baseline MVPA min/hr** | 25.1 (11.1) | 19.1 (4.9) | 17.7 (4.6) | 19.9 (4.6) | 17.0 (5.5) | 19.6 (6.8) |
| **After-School Club MVPA min/hr** | 8.8 (2.4) | 10.5 (4.1) | 10.0 (2.6) | 8.3 (2.3) | 8.2 (2.5) | 9.2 (3.0) |

Without controlling for any covariates, results showed that compared to baseline, girls, on average, significantly higher MVPA min/hr during the after-school club (5.34 min/hr and 9.24 min/hr, respectively) ($p<0.001$). Significant increases in average MVPA min/hr from baseline to after-school club remained when controlling for school attended (6.11 min/hr to 10.01 min/hr, respectively) ($p<0.001$) and when controlling for school attended and baseline MVPA (1.23 min/hr to 5.13 min/hr, respectively) ($p<0.001$) (Table 4.2 and 4.3). Specifically, every minute increase in average after-school MVPA min/hr at baseline was associated with a corresponding additional 3.90 minutes of MVPA min/hr during the PA club when controlling for school attended and overall baseline MVPA min/hr (ß=3.90 ± 0.31, $p<0.001$) (Table 4.3). Furthermore, girls who had higher overall MVPA min/hr at baseline were found to be significantly more active during PA club (ß=0.20 ± 0.03, $p<0.001$) (Table 4.3).

**Table 4.2: Regression comparing baseline after-school and after-school club MVPA while controlling for school attended**

| | Estimate | SE | t | p-value |
|---|---|---|---|---|
| **Intercept** | 6.11 | 0.46 | 13.16 | <0.001 |
| **Baseline MVPA min/hr during the Afterschool period** | 3.90 | 0.35 | 11.28 | <0.001 |
| **School B** | -0.50 | 0.58 | -0.87 | 0.39 |
| **School C** | -0.70 | 0.56 | -1.24 | 0.22 |
| **School D** | -1.37 | 0.57 | -2.40 | 0.02 |
| **School E** | -1.20 | 0.62 | -1.94 | 0.05 |

*significant p<0.01
**School A not listed in table, used as the reference school in the regression analysis

**Table 4.3: Regression comparing baseline after-school and after-school club MVPA while controlling for school attended and total baseline MVPA**

| | Estimate | SE | t | p-value |
|---|---|---|---|---|
| **Intercept** | 1.23 | 0.75 | 1.63 | 0.11 |
| **Baseline MVPA min/hr during the Afterschool Period** | 3.90 | 0.31 | 12.48 | <0.001* |
| **School B** | 0.66 | 0.53 | 1.25 | 0.21 |
| **School C** | 0.74 | 0.53 | 1.40 | 0.16 |
| **School D** | 0.36 | 0.52 | 0.69 | 0.49 |
| **School E** | 0.38 | 0.58 | 0.65 | 0.52 |
| **Total Baseline MVPA min/hr** | 0.20 | 0.03 | 7.72 | <0.001* |

*significant p<0.01
**School A not listed in table, used as the reference school in the regression analysis

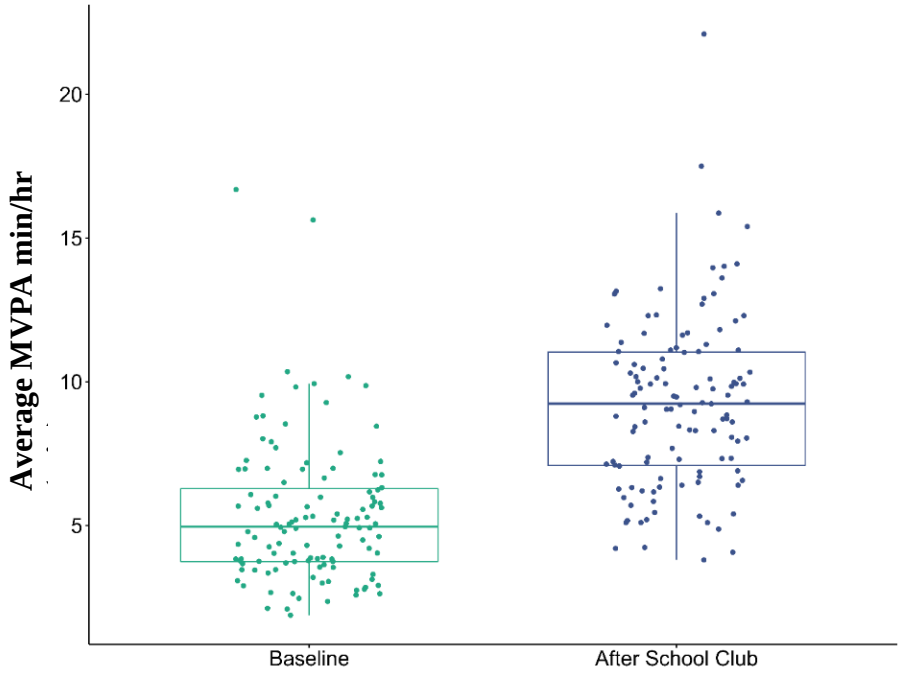


**Figure 4.1: Overall comparison of baseline after-school and after-school club MVPA (*significant difference, p<0.001)**

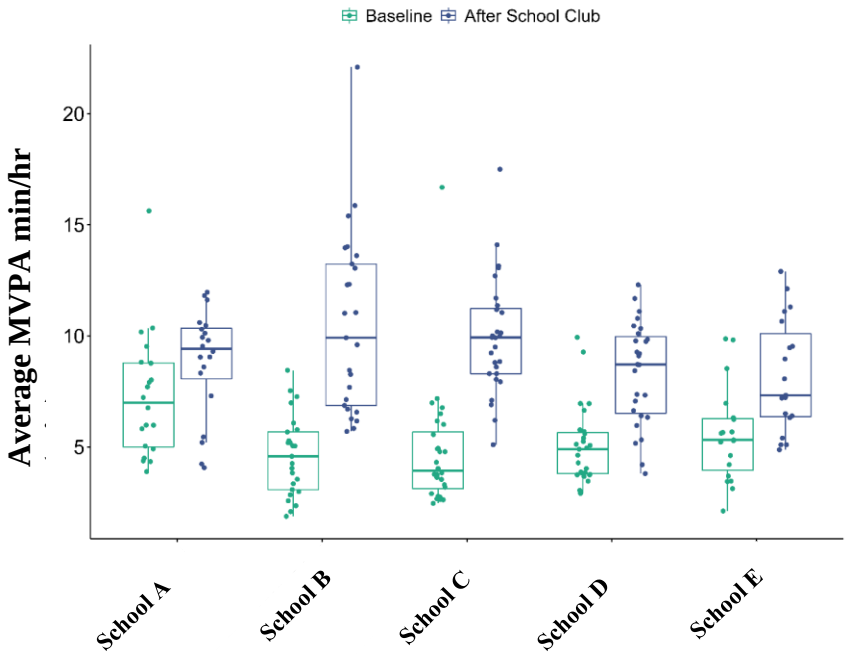


**Figure 4.2: Comparison of baseline after-school and after-school club MVPA by school**

Welches ANOVA showed no significant pairwise differences, after Bonferroni correction ($F_{4,54.56}$ =2.79, p=0.04), in change in average MVPA min/hr from baseline afterschool time to the GOTM after-school club among participating schools (Figure 4.3).

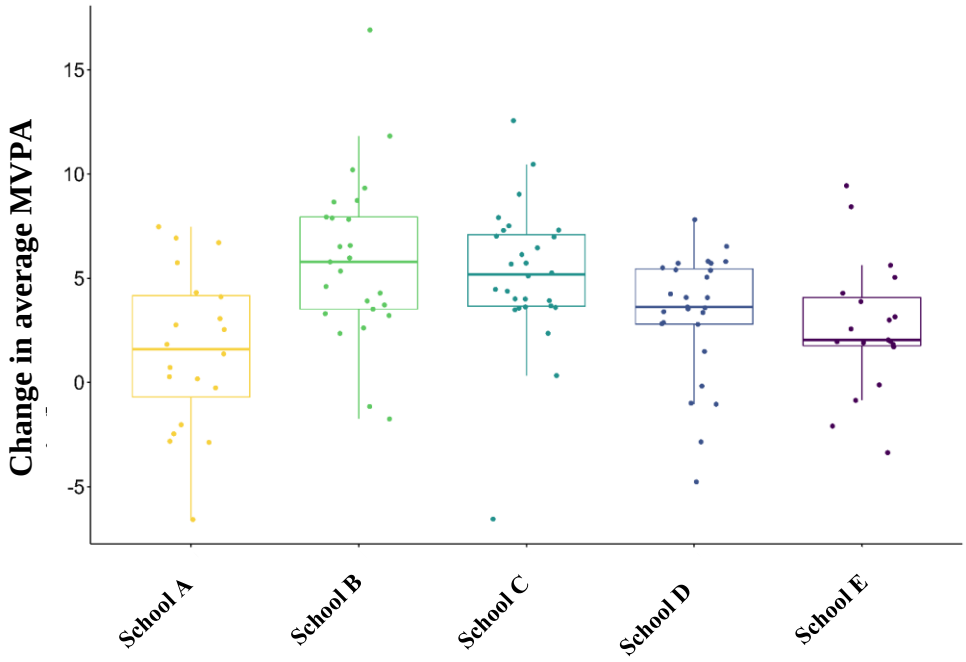


**Figure 4.3: Change in MVPA min/hr from Baseline afterschool time to PA Club time (no significant differences)**

Results also showed that the overall linear regression was found to be significant ($R^2$=0.26, F=3.433, df (11,107), p<0.001) (Table 4.4). Although there were no significant associations found between the average MVPA min/hr achieved during the after-school PA club and any of the participant factors of interest, there was evidence to suggest that earlier maturers (i.e., those in a late pubertal stage during the time of the intervention) were less active during the after-school PA club (p=0.05) (Table 4.4).

**Table 4.4: Associations between participant characteristics and after-school club MVPA**

| | Estimate | SE | t | p |
|---|---|---|---|---|
| **Intercept** | 2.53 | 13.43 | 0.19 | 0.85 |
| **Age** | 0.03 | 0.03 | 0.79 | 0.43 |
| **School B** | 2.93 | 1.00 | 2.94 | <0.001 |
| **School C** | 2.62 | 1.01 | 2.60 | 0.01 |
| **School D** | 0.78 | 1.24 | 0.63 | 0.53 |
| **School E** | 1.07 | 1.10 | 0.97 | 0.33 |
| **Black** | 0.95 | 0.63 | 1.52 | 0.13 |
| **Hispanic** | 0.32 | 0.87 | 0.37 | 0.72 |
| **Late pubertal Stage** | -1.19 | 0.61 | -1.95 | 0.05 |
| **Baseline VO2** | 0.03 | 0.21 | 0.16 | 0.87 |
| **Body fat** | -0.06 | 0.11 | -0.53 | 0.60 |
| **Baseline MVPA** | 0.11 | 0.04 | 2.66 | 0.01 |

$R^2$=0.26 F=3.433 df (11,107), p<0.001

**DISCUSSION**

In summary, a significant increase was observed in average MVPA min/hr from the after-school period at baseline to average MVPA min/hr during the after-school PA club, even when controlling for school attended and baseline MVPA (p<0.001). No significant difference was found in change in MVPA min/hr between the after-school period at baseline and PA club among schools. Also, there was a significant increase for average MVPA min/hr for girls from baseline to the PA club, and no significant associations found between this increase and the specific participant characteristics of interest. However, it seems that girls in the late pubertal stage were less active during the PA club than their peers in a later stage.

In general, although the GOTM intervention was not found to increase overall total daily MVPA, the current study clearly shows that the after-school PA club was successful at increasing MVPA during the after-school period across all schools included in the analyses.[15] Therefore, we accept hypothesis 1 that average MVPA min/hr during the after-school PA club

would be significantly higher than that achieved during the after-school period at baseline. It is unclear why the GOTM intervention did not increase total daily MVPA at post-intervention, but it is possible that positive increases were not seen due to the final 17-week measurement being conducted after the completion of the after-school PA club and not while it was still being implemented. In addition, because many of these girls lived in low SES areas with sparse resources and community safety concerns, removal of the intervention team and other resources for PA may have reduced their ability to attain MVPA through the end of the 17-weeks. [15,41,42]

These results give information about girls' temporal patterns of PA. Two PA patterns that have been previously identified in the literature include PA compensation and synergy. Also known as the activitystat hypothesis, PA compensation is the notion that youth compensate in their PA behavior with increased PA during one part of the day in response to a period of sedentary time during an adjacent time point (or vice versa) with the purpose of maintaining an innate total amount of PA.[6] PA synergy is a hypothesis in opposition to PA compensation which suggests that youth rarely compensate, but rather, remain consistent in their PA behavior and most often follow-up a time of high (or low) PA with additional periods of high (or low) PA.[7] Current literature fails to suggest which of these patterns occurs most often—if both occur at different points across the days and weeks or if these patterns are variable dependent on individual characteristics. However, similar to previous literature conducted by Dale et al., 2000, Long et al., 2013, and Goodman et al., 2011—this study exhibits evidence for PA synergy, as girls who were most active at baseline, both overall and during the after-school period, were found to also have higher MVPA during the after-school PA club (Table 4.2.). This highlights the need for future after-school interventions to focus PA promotion efforts on youth who are not normally active during this time of the day, as results suggest that girls who are highly active will

remain highly active, and those who are not as active continue to be less active. A possible solution to disrupt this maintenance of PA levels, especially for those who are less active, could be to implement new school-based interventions and programs to provide more opportunities for girls to be active during the largely sedentary school day.

We also accept hypothesis 2, that there would be no differences between schools in average MVPA min/hr achieved during the after-school PA club. Additionally, results showed that, there were no significant differences in the change in average MVPA min/hr from baseline after-school time to the after-school PA club among participating schools. Schools that had higher MVPA min/hr during baseline after-school time also had higher MVPA min/hr during the after-school PA club. This demonstrates that the GOTM intervention was delivered consistently from school to school, supporting evidence previously reported in past GOTM publications. Fidelity was found to be high, and the after-school program was found to well-received by participants and delivered with high quality from school to school even though differences between schools existed (e.g., coach/manager expertise, available equipment, available space, attendance, and demographics).[15,16]

Hypothesis 3 states that body fat percentage, cardiorespiratory fitness, age, pubertal stage, and race/ethnicity would all be significantly associated with average MVPA min/hr during the after-school club. We reject this hypothesis as results show no significant associations for the factors of interest. It is worth noting that girls in the late-pubertal stage in this study) exhibited lower amounts of after-school club MVPA min/hr approaching significance ($p=0.05$). This is a finding that is in line with previous literature.[44,45,46,47] Baker et al. 2007., found that early maturing girls in comparison to later maturing girls, achieved on average 6.07 fewer min/day (42 min/wk.), of MVPA and 2.17 per day, in later pubertal stages than their later maturing

peers.[47] Gammon et al. 2017, who examined PA by pubertal stage in the GOTM study at baseline also found that girls' PA levels were significantly different across different pubertal categories. Girls in the early stages of pubertal development engaged in the highest levels of light, moderate, and vigorous PA and girls in late pubertal stages engaged in the lowest.[44]

**Limitations**

The sample of all girls in urban schools in low SES areas could be viewed as a limitation as it restricts generalizability to all youth. The after-school program had a relatively short study duration in which only one week of PA data were collected at baseline, some girls only had one day of PA club data and others hand multiple, making comparison difficult. Future research should address these limitations by including boys and examining participants in different locations to further our knowledge of PA during the after-school period and overall PA patterns for youth. Future research should also strive to examine after-school PA over longer periods of time, develop new and innovative programs and interventions for increasing PA, and to attempt to further characterize how different participant factors may be predictive of PA during specific time periods.

**Strengths**

Despite these limitations, the current study also has many strengths. Although also listed as a limitation, the study's sample of high percentage of girls who were from minority racial/ethnic groups, low socioeconomic status (SES), and living in urban areas could also be considered a strength, as these girls have been identified by previous literature as being at a high risk for inactivity. [8,9,10,11,12,13,14,30,31,32,33] This study had control over and knowledge of activities that were being performed during the afterschool club in different schools, leading to high participant satisfaction and study fidelity. This study was also able to confirm that although

GOTM was not able to increase overall MVPA of these girls at the post-intervention timepoint, it was successful in increasing after-school MVPA through the implementation of the GOTM PA Club. Thus, afterschool PA interventions can be a quality way of increasing PA during specific times of the day in low-income/high minority communities.

**Conclusion**

In conclusion, it is clear that more research is needed to examine different ways to promote physical activity during different times of the day in adolescent girls. It is crucial to continue to develop strategies to promote PA during times of the day that may have the most influence on overall PA behavior. Although this study focused on the after-school period, more research into other periods of the day such as before-school and during-school time is warranted. A deeper dive into when youth are active and how PA during one part of the day may influence another may lend valuable information to develop new strategies for promotion and PA interventions with the hopes of eventually increasing overall PA. Furthermore, this study did not find that any of the participant factors of interest were predictive of PA levels during the after-school period. It is, however, strongly suspected that further examination of these individual participant factors, specifically maturity status, over a longer period may lend insight into characteristics that promoters and researchers can identify to help focus efforts to increase youth PA and hopefully the overall health of youth in the United States.

**Table S.3: Power Analysis Table for Different Effect Sizes**

| Effect Size | Predicted Power |
|---|---|
| 0.2 | 58% |
| 0.4 | 97% |
| 0.6 | 99% |
| 0.8 | 99% |

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# Chapter 5: Final Discussion

## Temporal Patterns of Physical Activity in Youth

Michael J. Wierenga

The overall purposes of this dissertation were to summarize the existing literature concerning temporal patterns of PA in youth and to examine temporal patterns at different times and in different settings amongst middle school-aged girls in the GOTM intervention study**.**

***A Systematic Review of the Temporal Patterns of Physical Activity in Youth (Manuscript 1)***

Through an in depth look at previous literature, the systematic review (Manuscript 1) first identified and summarized the existing literature on temporal patterns of physical PA in youth, and second, made suggestions for the future to identify optimal times to improve PA promotion strategies and eventually, the overall health of our youth. The systematic review revealed that a wide variety of studies exist examining different participant factors and time periods during the days, weeks, months, and seasons, many of which focused on weekday PA, specifically during the school day. Common patterns in the literature include compensation and synergy. Evidence for both compensation[1,2,3,4,5,6,7,8] and synergy [9,10,11,12,13,14,15] were found in multiple studies from the systematic review. Lack of agreement with respect to the existence of synergy and compensation between researchers is concerning and highlights that a focus on compensation or synergy may not be the best approach to be adopted by future research. Many other short term PA patterns were also examined such as within-day, day-to-day, and long-term patterns like week-to-week and longitudinal (longer than a year). Future research should aim to examine these patterns if we are to truly characterize which patterns youth follow and what factors affect their behavior. It seems that regardless of the pattern examined, many studies found youth PA patterns, and habitual PA in general, to be highly variable and often dependent on the school day schedule and structure, other active events during the day (i.e., PE, recess, Sports participation, or after-school programs), and individual participant characteristics (i.e., age, sex, race/ethnicity, body composition, cardiorespiratory fitness).[35,36,37,38,39]

Although more information regarding short-term PA patterns is needed and could be beneficial in aiding to increase overall PA achieved by youth, future studies may be better served to examine temporal patterns for longer periods of time (i.e., months/years rather than days/weeks). Longer term studies specifically focused on examining temporal patterns of youth PA could be more adept at summarizing existing patterns as they change and develop from month to month and season to season. PA interventions and programs, during the school day and at other meaningful times during the day, represent a quality avenue to track youth PA over a longer time-period. This would allow for a more accurate representation of PA patterns and the integration of meaningful bouts of PA to normally sedentary classroom activities to help youth meet PA guidelines.

### *School-Day Temporal Patterns of Physical Activity in a Racially Diverse, Low SES Sample of Girls (Manuscript 2)*

Previous literature has identified certain disparities in the PA behavior of youth.[16,17,18,19,20,21] Girls and racial/ethnic minorities in urban and low SES areas may be at highest risk for low PA.[22,23,24,25,26,27] This dissertation used data from the GOTM intervention to examine temporal patterns during the school day to gather information on how to better utilize patterns and promote PA in these individuals. Through an examination of girls PA behavior from GOTM, Manuscript 2 provided evidence for compensation within-days—PA rose and fell over the course of the day. Overall average MVPA min/hr was highest during the before-school period (6.11 min/hr). It dropped during school-time hours to 2.98 min/hr, and then rose again during the afterschool and evening periods (5.27 min/hr, 4.84 min/hr, respectively). This compensational pattern throughout the school day is, most likely, due to the typical school day schedule. Results indicated that there was a significant positive association among all four time-periods ($p<0.001$), suggesting that girls with higher activity levels stayed more active throughout

the day and girls with lower activity levels stayed less active. This consistency in PA levels posits evidence for synergy. These findings for both compensation and synergy highlight that these terms may not, then, be appropriate for describing true, habitual temporal patterns of PA. Compensation may not be a habitual PA pattern and varies within a day or even day-to-day most simply because of the school day schedule and other planned, active events during the day. Synergy seems to be a pattern that is more reflective of true habitual PA patterns over longer amounts of time, and individuals who exhibit high or low PA levels over the course of days and weeks seem to maintain the same level of PA over longer months, seasons, and years relative to their peers. This realization is in accordance with previous literature from Telema et al. 2005, who found that PA behavior tracks longitudinally from childhood all the way into adulthood. Youth who exhibit low activity levels during childhood usually become more sedentary adults, and highly active children transition synergistically into active adults. It is suggested, therefore, that future research replace an examination of *which* of these patterns happens, with an examination of *when* each of these patterns happens.

It seems evident that the school day is a driving force in determining PA levels for youth. Because of this, researchers should continue to develop new promotional strategies, as well as new and innovative programs and interventions. PA both during the school day and during other important times of the day like the after-school period should be a focus for future programs and interventions. Although the school day structure may not be something that can be completely changed to remove sedentary time, the goal of researchers, promoters, and teachers should be to lessen the compensatory fluctuation throughout the day by providing more opportunities for youth to be active in the classroom. The end goal is to increase overall daily PA levels and help youth meet the guidelines for youth PA of 60 minutes per day, but it is also to create more active

youth across the board so that natural synergistic behavior helps youth transition from a more active childhood to an active and healthy adult life.

### *Comparing After-School Physical Activity Patterns Prior to and During an After-School Program in the Girls On the Move Intervention (Manuscript 3)*

The after-school period has been identified in previous literature as an important part of day in determining overall youth PA and a quality time for focused health promotion and intervention.[40] Manuscript 3 aimed to characterize PA levels during the after-school period prior to and during an after-school program in GOTM. In general, the GOTM intervention was not found to increase overall total daily MVPA[27,29], but Manuscript 3 clearly shows that the GOTM after-school PA club was successful at increasing MVPA during the after-school period across all participating schools examined. This finding is both encouraging and informative as it posits evidence that an after-school PA program can be successful at increasing PA levels. It is unclear why the GOTM intervention did not increase total daily MVPA at post-intervention, but it is possible that positive increases were not seen due to the final 17-week measurement being conducted after the completion of the after-school PA club and not while it was still being implemented. Many of these girls also lived in low SES areas with sparse resources and community safety concerns, therefore removal of the intervention team and other resources for PA may have reduced their ability to attain MVPA through the end of the 17-weeks.

Like Manuscript 2, this study also found evidence for synergistic PA behavior. Girls who were most active at baseline, both overall and during the after-school period, were found to also have higher MVPA during the after-school PA club. This finding highlights the need for future afterschool interventions to focus PA promotion efforts on youth who are not normally active during this time of the day, as results suggest that girls who are highly active will remain highly active, and those who are not as active continue to be less active. In order to disrupt this pattern

of maintenance of PA levels for those who are less active, it is important for future researchers and health promoters to implement new school-based interventions and programs to provide more opportunities for girls to be active during the largely sedentary school day.

No associations were found between participant characteristics (i.e., body fat percentage, cardiorespiratory fitness, age, pubertal stage, and race/ethnicity) and an increase from baseline after-school PA to PA during the after-school club. It is suspected that examination of PA during the after-school period over a longer study duration would lead to better characterization of which factors are associated with increased MVPA during this time. It is important to address, however, that maturation status was found to be associated with MVPA min/hr achieved during the club (approaching significance, p=0.05). Those who were in a later stage of maturation were found to have lower amounts of afterschool club MVPA min/hr than their later maturing peers, approaching significance (p=0.05). This finding is in accordance with previous literature (cite).[31,32,33,34] PA levels, especially for girls, seem to decrease as they mature.[41,42] Future research should not only focus on increasing PA for those in later maturation stages during the after-school period, but also at all other time-points during the day. It is strongly suspected that an examination of associations between participant characteristics and PA during different times of the day over a longer study duration would yield significant results. Therefore, future studies examining temporal patterns of PA should take a deeper dive into when youth are active and how PA during one part of the day may influence others. This information may lend valuable information to develop new strategies and new interventions to increase PA during different times of the day, with the hopes of eventually increasing overall PA.

## Conclusion

This dissertation presents a comprehensive examination of the temporal patterns of physical activity in youth, focusing on middle school-aged girls in the Girls On The Move (GOTM) intervention study. The primary aim of this dissertation was to summarize existing literature concerning temporal patterns of PA in youth and to examine these patterns in various times and settings, highlighting different factors affecting youth activity levels.

Manuscript 1 provides a systematic review of the literature on temporal patterns of PA in youth, revealing that compensation and synergy are seen in multiple studies. Manuscript 2 examines school-day temporal patterns of PA in a low SES, racially diverse sample of girls, highlighting the importance of both compensation and synergy behavior in determining activity levels. Finally, Manuscript 3 characterizes after-school PA patterns in the GOTM intervention, with positive implications for after-school PA programs.

This dissertation furthers our understanding of youth PA patterns. It highlights that pre-established patterns, such as time spent in PA through compensation or synergy, focused on by previous literature, may not be the question to the answers we need. Youth can be both compensatory and synergistic dependent on individual, social, and environmental characteristics, in addition to age, maturity status, race/ethnicity, and biological sex. Synergistic PA is more maintenance of PA over time while compensation is a daily fluctuation due to schedule, school-day structure, and irregular events. Synergy of high amounts of PA is the pattern that we want children, and also adults, to adopt. Rather than focusing on which of these patterns happen, however, researchers should strive to improve short term patterns, thereby reducing school-day compensation, by offering more opportunities to be active throughout the day so that healthy synergistic behavior can be developed and maintained into adulthood.

This dissertation also shows that maturity status may be a key factor that influences temporal patterns. If we truly want to develop and maintain consistent PA and MVPA patterns from youth to adulthood, we must do further research to determine which interventions at which ages and maturity levels will have the most impact long term. Future research should also look at longer term (more than a year) interventions that examine PA behavior by trying to reduce the degree of school day compensation, by offering more opportunities to be active during the day with the hopes of engraining more synergistic behavior. Opportunities for synergistic PA at a higher duration/frequency/intensity may help those who are not usually active to bring them to a higher level of PA into adulthood.

In conclusion, this dissertation underscores the need for future research to better understand temporal patterns of physical activity in youth. It provides insight into how the school day structure is a driving force in the activity level of youth, highlighting the need for appropriate promotional strategies and innovative school-based interventions to increase overall PA levels. By taking a deeper dive into when youth are active and how other participant factors influence this behavior, researchers can create more effective interventions to help youth become more active and promote more habitual synergistic PA behavior to help children become healthy, active adults.

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