Summer 8-14-2015

School Design to Promote Physical Activity

Jeri Brittin
University of Nebraska Medical Center

SCHOOL DESIGN TO PROMOTE PHYSICAL ACTIVITY

by

Jeri Brittin

A DISSERTATION

Presented to the Faculty of

The Graduate College in the University of Nebraska

In Partial Fulfillment of the Requirements

For the Degree of Doctor of Philosophy

Health Promotion and Disease Prevention Research
Graduate Program

Under the Supervision of Professor Terry T.-K. Huang

University of Nebraska Medical Center
Omaha, Nebraska

July, 2015

Supervisory Committee:

Kendra Schmid, Ph.D. Debra Romberger, M.D.

Mohammad Siahpush, Ph.D. James Leighter, Ph.D.

Sheila Elijah-Barnwell, Ph.D., AIA

"Health and salvation can only be found in motion."

-- Søren Kierkegaard

ACKNOWLEDGEMENTS

My heartfelt gratitude goes to my advisor, Terry T.-K. Huang (UNMC and City University of New York), and to my committee members Debra Romberger (UNMC), Mohammad Siahpush (UNMC), Kendra Schmid (UNMC), James (Jay) Leighter (Creighton University), and Sheila Elijah-Barnwell (HDR), for their ongoing and inestimable support throughout my doctoral work.

I extend my gratitude as well to the other insightful colleagues and mentors who played various roles in my research over the past few years: Leah Frerichs (University of North Carolina-Chapel Hill), Matthew Trowbridge (University of Virginia), Ozgur Araz (UNMC), John Sirard (University of Massachusetts-Amherst), Dina Sorensen (VMDO Architects), Nancy M. Wells (Cornell University), Beth Myers (Cornell University), Andrew Jameton (UNMC), Virginia Aita (UNMC), Christopher Fisher (Curtin University, Australia), Dieter Breithecker (Federal Institute for Posture and Mobilisation Support, Germany), Karen K. Lee (New York City Department of Health and Mental Hygiene), Adrián Ramírez-Nafarrate (Instituto Tecnológico Autónomo de México), Jeanette Garcia (Harvard University), Ghada Soliman (UNMC), Gleb Haynatzki (UNMC), Biaojang Chen (UNMC), Melissa Tibbitts (UNMC), Tricia LeVan (UNMC),Timothy Hemsath (University of Nebraska-Lincoln), Lindsey Bahe (University of Nebraska-Lincoln), and Betsy Gabb (University of Nebraska-Lincoln). I also thank Katherine Ankerson (Kansas State University) and Doug Amedeo (University of Nebraska-Lincoln) for having the insight to encourage me to pursue a public health Ph.D. in the first place.

The research presented in Chapters 1 and 2 was possible thanks to the cooperation and support of the students, teachers, staff, administration, and school community at the Carter G. Woodson Education Complex in Buckingham County, Virginia.

The research presented in Chapter 2 was partially supported by funding from Youth-Nex, the Center to Promote Effective Youth Development at the University of Virginia. The New York data collection was funded in part by the Robert Wood Johnson Foundation through its Active Living Research Program (#69550). Federal funding was provided by the U.S. Department of Agriculture (USDA) through the Food & Nutrition Service (FNS) People's Garden pilot program (Project #CN-CGP-11-0047) and by the Cornell University Agricultural Experiment Station (Hatch funds) (#NYC-327- 465) and Cornell Cooperative Extension (Smith Lever funds) through the National Institutes for Food and Agriculture (NIFA) USDA. Additional funding for the study of gardens and physical activity came from: Cornell University's Atkinson Center for a Sustainable Future (ACSF); The College of Human Ecology, Cornell University; The Bronfenbrenner Center for Translational Research (BCTR), Cornell University; and the Cornell Cooperative Extension Summer Intern Program.

Finally, thanks to Ben, Tricia, and my family and friends for their patience and encouragement.

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Jeri Brittin, Ph.D., M.M., Allied ASID

University of Nebraska, 2015

Supervisor: Terry T.-K. Huang, Ph.D., M.P.H., C.P.H.

Increasing children's physical activity (PA) at school is a national focus to address childhood obesity. Research has demonstrated associations between school built environments and students' PA, but has lacked a comprehensive synthesis of evidence. Chapter 1 presents new evidence-, theory-, and practice-informed school design guidelines, including evidence substantiality ratings, to promote PA in school communities. These guidelines delineate strategies for school designers, planners, and educators to create K-12 school environments conducive to PA. They also engage public health scientists in needed transdisciplinary perspectives.

There have been few longitudinal studies to verify causal relationships between the school built environment and PA. Chapter 2 presents results from a natural experiment with objective PA-related measures before and after a move to a new K-5 school designed based on the Chapter 1 guidelines. The study hypothesized that the school would have desirable impacts on students' sedentary behaviors and PA. The intervention school group was compared longitudinally with a demographically-similar group at 2 control schools. School-time analyses showed that the intervention school design had positive impact on accumulation of sedentary time, and time in light PA, likely due to movement-promoting classroom design.

Studies of built environment impacts on human behaviors and health have presented challenges in control of confounding effects. Chapter 3 presents results from experiments using an agent based model (ABM) to simulate population samples of

children and to quantify the impact of a single design intervention, dynamic furniture in school, on obesity and overweight prevalence over time. Results of computational experiments showed that there could be some desirable population impact among girls with low PA profiles.

Chapter 4 places the work presented in Chapters 1-3 in a larger context. Via exploration of theories of space as a social phenomenon, of design as a discipline in need of human purpose, and of the limitations of current public health built environment studies, the investigator proposes key strategies toward achieving substantial unrealized potential to design our built environments to achieve health.

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LIST OF ABBREVIATIONS

PA	physical activity
LPA	light physical activity
MVPA	moderate to vigorous physical activity
MPA	moderate physical activity
VPA	vigorous physical activity
RCT	randomized controlled trial

CHAPTER 1

Comprehensive Review and
Physical Activity Design Guidelines for School Architecture

Note: A version of this chapter was published
in the journal *PLoS ONE* on July 31, 2015.

ABSTRACT

Increasing children's physical activity at school has become a national focus in the U.S. to address childhood obesity. While research has demonstrated associations between aspects of school environments and students' physical activity, the literature currently lacks a synthesis of evidence to serve as a practical, spatially-organized resource for school designers and decision-makers, as well as to point to pertinent research opportunities. This paper describes the development of and presents a new practical tool: *Physical Activity Design Guidelines for School Architecture*. Its aims are to provide architects and designers, as well as school planners, educators, and public health professionals, with strategies for making K-12 school environments conducive to healthy physical activity, and to engage scientists in transdisciplinary perspectives toward improved knowledge of the school environment's impact. The investigator led a qualitative review process to develop evidence-based and theory-driven school design guidelines that promote increased physical activity among students. The design guidelines include specific strategies in 10 school design domains. Implementation of the guidelines is expected to enable students to adopt healthier physical activity behaviors. The tool bridges a translational gap between research and environmental design practice, and may contribute to setting new industry and education standards.

BACKGROUND

Physical activity (PA), health, mental alertness, and quality of life are closely interconnected, and the human body needs regular PA in order to function optimally. Evidence is emerging as to the association between children's PA and academic achievement [1-3], and a substantial body of literature has demonstrated associations between children's PA and current and future health status, including obesity and related diseases [4]. Obesity is a major risk factor for chronic diseases including type 2 diabetes and heart disease, as well as various types of cancer affecting the breast, endometrium, kidney, colon, and esophagus. In the U.S., childhood obesity prevalence tripled between 1980 and 2000 [5], with one-third of U.S. children and youth being overweight or obese today [6]. Concomitantly, very few children achieve the current U.S. recommended minimum of 60 minutes per day of moderate to vigorous physical activity (MVPA) [7-9].

In recent years, research on childhood obesity has increasingly focused on transdisciplinary approaches [10], and ecological models with environmental correlates [11], as individually-focused prevention and treatment efforts promoting activity and dietary behavioral change have been difficult to sustain and have had relatively little population-level impact [12,13]. In public health, the built environment has been conceptualized to contain environmental domains – physical, legal, policy, social and cultural – that influence health-related behaviors [14-16]. Theories from several fields of inquiry – including proxemics, architectural theory, environmental psychology, and behavioral geography – have posited that the physical or 'built' environment and human behaviors are interrelated, and that physical and social environments are intrinsically linked [17-22]. In addition, social theories have contributed concepts, such as observational learning and environmental determinism, which posit that people can learn new behaviors via exposure to modeling and to environmental change [23,24], and that social structure and human action are interdependent in time and space [25].

Building upon theoretical notions of environment-behavior relationships, studies have focused on the relationships between children's PA and neighborhood environment characteristics [26], as well as the school classroom environment's impact on teacher and student behaviors and psychosocial outcomes [27,28]. Past research has indicated that school settings have both direct and mediated impact on learning and achievement outcomes [39,30], and a number of studies have focused on connections between school environmental variables and student learning outcomes [31-36].

Some scientists have suggested that the obesity epidemic is related to "chair-enticing environments," and have recommended policy changes to promote default PA in school, home and work environments [37]. Interventions to reduce overall time in sedentary behaviors [38], as well as to alter the manner of sedentary time accumulation may be important, as breaks in sedentary behavior have been positively associated with lower body mass index (BMI), and better blood lipids and glucose tolerance [39]. In addition, research has shown that increases in energy expended in everyday activities other than sports-type exercise can impact overall energy balance and can provide protection against fat gain and obesity [40-42]. Environmental design can potentially play a role in supporting such everyday activities.

Based upon associations between aspects of the built environment and health, many have recommended built environment regulatory and non-regulatory policy strategies intended to increase health-promoting behaviors. National and local initiatives are addressing the problem of U.S. populations' physical inactivity: "Healthy and safe community environments" is one of four major strategic directions of the National Prevention Strategy, focusing on transforming community settings, including schools, to make healthy choices the "easy" choices. National Prevention Strategy recommendations include integration of health criteria into decision-making across relevant sectors, identifying and implementing proven strategies, and conducting research in areas where evidence is not clear [43]. The City of New York has implemented *Active Design Guidelines* to promote active and healthy living among its residents [44,45]. It has also worked with partners to develop safety strategies for active living [46], and active living housing approaches [47]. The National Collaborative on Childhood Obesity Research (NCCOR), in cooperation with the American Institute of Architects (AIA) and the U.S. Green Building Council (USGBC), has recommended development of evidence-based guidelines for the building industry to promote PA [48]. In partnership with the City of New York, the USGBC has also created a Leadership in Energy and Environmental Design (LEED) green building rating system pilot credit, “Design for Active Occupants,” [49] and is developing an Active Design Index [50].

Schools have been consistently highlighted as important venues for policy-level decisions that impact the health of youth [4,51-54]. A 2012 Institute of Medicine (IOM) report noted that “[c]hildren spend up to half their waking hours in school. In an increasingly sedentary world, schools therefore provide the best opportunity for a population-based approach for increasing PA among the nation’s youth” [55] (p.333). Thus, increasing children’s PA in the school environment is now a national priority to address childhood obesity. A 2013 IOM report further emphasized the need to develop high-quality research on the influence of school design on children’s PA and to embrace a “whole-of-school” approach to childhood obesity [4]. Research has indicated that children were sedentary during 70% of class time, including PE class, and that most children also remained sedentary during break and lunchtime [56], highlighting a substantial opportunity to increase PA during the school day. Correlation between school-based physical education (PE) curricula and overall student PA has been documented [57]. Moreover, studies have shown that emphasis of PA in the school curriculum more broadly, i.e., not just in PE class, was beneficial to students' overall health, social well being, and academic achievement [1,58].

Multi-component, evidence-based school PA interventions, often focusing on PE curricula and including regular activity breaks and family strategies, have been most effective in children [59], but the literature is not clear as to the direct, mediating, or modifying impacts of the built or physical school environment in such interventions. Collaborative work in public health and architecture has pointed to the potential for school design to play a substantial role in obesity prevention [15,60]. However, while there is a growing body of research pertaining to PA-related outcomes and the school physical environment, findings from this work have not been consolidated with the intent of informing school design practice and research.

The billions spent annually in the U.S on public school construction, including new schools, additions, and renovations [61], represent opportunities both to implement evidence-supported health-promoting school designs to reach diverse populations of children, and to develop research opportunities that improve the evidence base. In order to leverage these opportunities, designers and decision-makers need succinct and reliable resources from which to draw, and scientists need to engage in influencing and evaluating the facility-related decisions designers, school administrators, and school communities make.

The *Healthy Eating Design Guidelines for School Architecture* introduced design strategies in school spatial domains to encourage healthy eating behaviors among school communities [62,63]. Here we present a complementary practical synthesis of theory- and evidence-supported school design strategies, in 10 design domains, to promote healthy PA behaviors in school communities. The aims of these *Physical*

Activity Design Guidelines for School Architecture are to serve both as a reference for current evidence-supported school design practice to promote PA, and as a source for researchers to generate testable hypotheses for future studies as to the impact of school designs on child and adolescent PA outcomes.

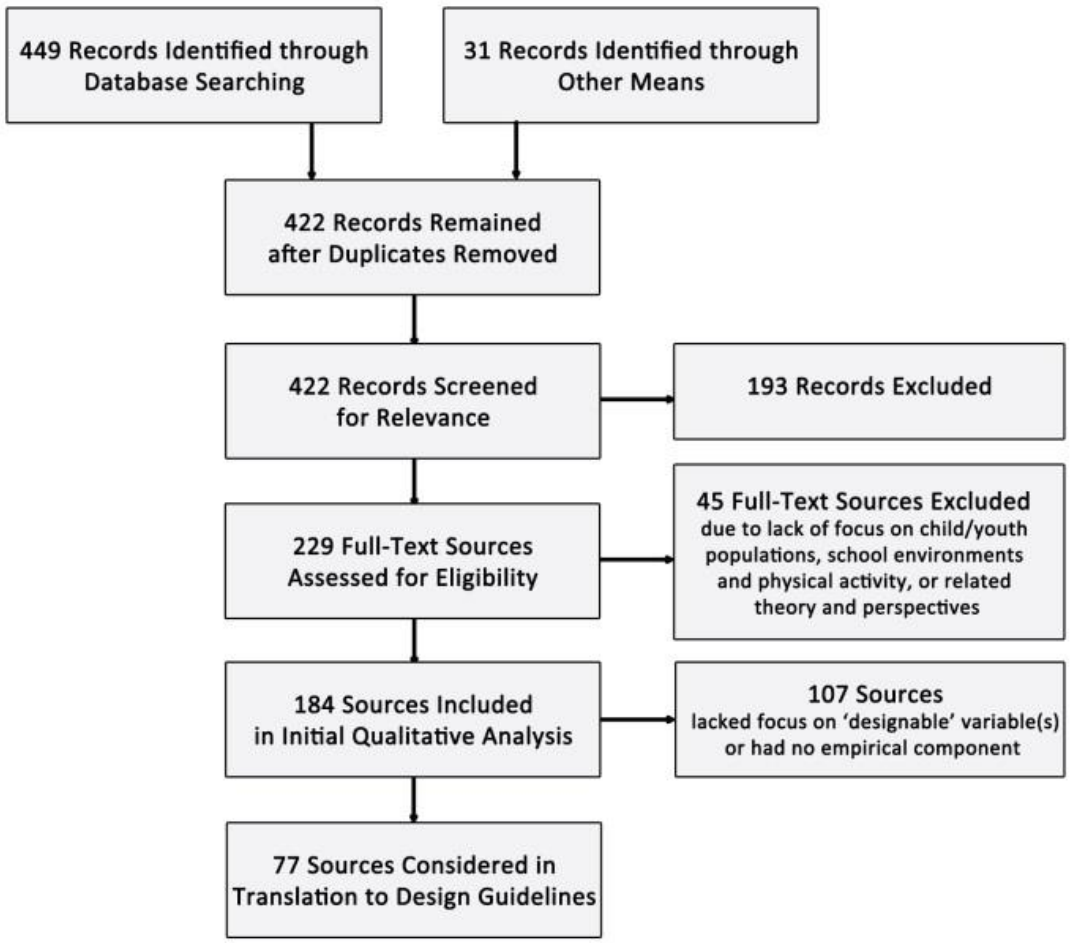
METHODS

Literature Search

The investigator conducted a comprehensive literature search encompassing K-12 school physical or 'built' designs and characteristics, and student PA-related outcomes. Our intention was not to determine or quantify a relationship between a pair of discreetly defined and measured variables, but rather to cover the breadth of research that could have bearing on the development of a translational tool to support both design practitioners and scientists wishing to build upon the evidence base informing PA-promoting school design. We searched the following databases: PubMed/Medline, psycINFO, CINAHL, ERIC, Physical Education Index, Avery Index to Architectural Periodicals, and Educational Administration Abstracts. In PubMed, we employed Medical Subject Headings (MeSH) code, using the following search structure: (Schools[mesh] OR school*) AND ("facility design and construction"[mesh] OR architecture OR "environment design"[mesh] OR "city planning"[mesh] OR "school design" OR "building design" OR "built environment") AND (exercise[mesh] OR obesity/prevention and control[mesh] OR "health promotion"[mesh] OR "physical activity"). In addition, we conducted a title/abstract [tiab] search of PubMed. For databases not using MeSH, we used a somewhat broader and more simplified keyword structure based on the above, so as to ensure comprehensive coverage of work pertaining to school physical environment variables and PA. Searches included literature through June 2014. One abstract reference was subsequently updated when the full-text article became available [64], and one study in review was subsequently published as an abstract [65]. Additional pertinent references were identified from relevant knowledge domains (e.g., environmental and social psychology, architectural theory, behavioral geography), and in reference lists of individual sources.

The investigator identified 422 unique sources as potentially relevant to the topic of designing K-12 schools to promote PA. Sources were generally excluded that did not pertain to child or adolescent populations, and schools and surrounding environments, unless the work pertained to specific environmental variables or issues of relevance where similar focus on children's PA and K-12 schools was not available. A few studies of preschoolers aged 4 to 6 years were included, as this age range largely overlaps the age range for Kindergarten and 1st grade in the U.S.; studies of preschoolers younger than age 4 were excluded. Also included were a few studies in university and other buildings, where environmental variables were of interest, and K-12 school-based studies were not available. In particular, these studies addressed stair usage mainly by adults in several stair intervention scenarios. In order to be inclusive of practice-based outcomes-oriented thinking related to schools, we initially reviewed articles in the architectural literature focusing on learning outcomes in children. However, since these school-related articles did not address PA, they were excluded from the final set of literature. We included one study with the outcome of fat mass index that pertained to active commuting and built environment associations, one study of learning outcomes that were related to school physical environment features and concomitant student PA, and one study of walkability around schools based upon neighborhood-level secondary data. Although the search was generally limited to English-language articles, we included 2 relevant German studies that have not been translated to English. Of 229 full-text sources assessed, 184 were retained for qualitative review. Translation to the design guidelines focused on 77 sources that were empirical studies or reviews of empirical work, and that pertained to physical environmental variables that could potentially be designed by practitioners (Figure 1.1).

Figure 1.1. Diagram of Source Inclusion/Exclusion Process.



Transdisciplinary Team and Development of Core Principles

The investigator led a core team of public health scientists and design practitioners based on the premise that neither group could adequately address development of health-promoting school environments by working solely in disciplinary silos, and with a conviction that there would be benefits to engaging in the challenges of transdisciplinary collaboration. Such challenges have been discussed elsewhere [62]. The review team consisted of professionals in public health academics and practice, and in architectural and interior design, with the investigator having formal training in both design and public health research. Team members' areas of expertise included school architecture and the design of learning environments, the role of PA in healthy childhood development, obesity prevention and intervention research, and designing healthy communities. As a foundation for our intended development of school design guidelines, we formulated a set of core principles as follows:

1. Maximize opportunities for PA (both unintentional and intentional) as part of the school routine.
2. Consider school spaces and features as opportunities to promote children's natural inclination to move, play, and explore.
3. Apply theory- and evidence-based behavioral science practice to enable the school community to engage in higher levels of default PA.
4. Conceive and articulate school spaces as community assets, and identify nearby community spaces as school assets, to multiply the benefits of school-based healthy PA initiatives.
5. Leverage inherent synergies with current trends in sustainable and universal design, which respectively define good design based on sensitivity to environmental impacts, and accommodation of all user needs and perspectives.

Synthesis and Translation from Research Findings to the Guidelines

The investigator qualitatively analyzed literature sources to identify source/study types and designs, sample characteristics, approaches and measures, and key findings, and then engaged in an iterative process of summarizing and synthesizing the findings, assessing relative strengths of evidence, and considering best to translate evidence to a structure that would be of practical use both to school designers and to scientists wishing to further knowledge as to health-promoting school environments. The investigator and team simultaneously asked the questions, “What does the evidence tell us about designing schools to promote PA?” and “What do design practitioners need to know to create schools that promote PA?” We found that the answers to the first question often do not sufficiently answer the second question, supporting a need for both scientists and designers to engage in the other group’s knowledge bases and perspectives. Our ‘translational’ efforts were thus bi-directional, intended not only to translate science to practice, but also to bring practice perspectives to science.

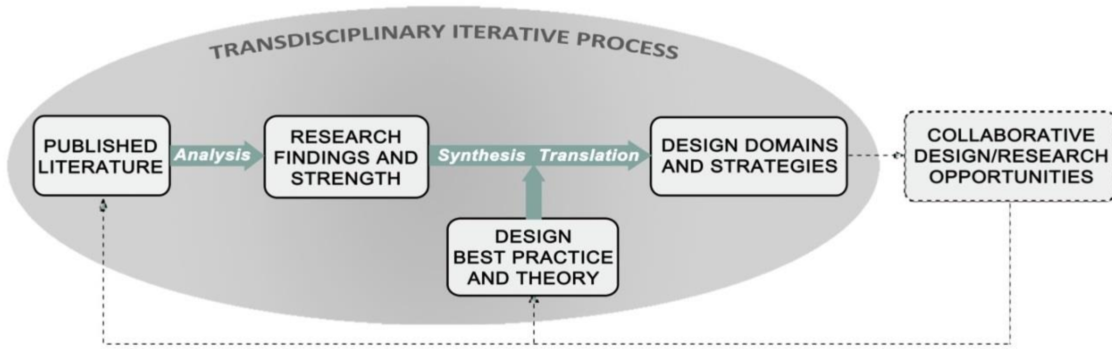
The investigator rated individual studies’ strength of evidence based on research designs and sampling approaches at 3 levels: Strong, Moderate, or Preliminary:

- Strong evidence came from longitudinal cluster randomized or cluster matched controlled trials with measures over time in more than one locale.
- Moderate evidence came from longitudinal approaches with smaller, single-site samples and a comparison or control group, from cross-sectional designs with a large and/or random sample, and reviews consolidating evidence from such studies.
- Preliminary evidence came from single-site longitudinal designs lacking a control or comparison group, and from small pilot cross-sectional associational studies.

Correlates of and causal factors for PA addressed in this set of studies were wide-ranging, sometimes addressed by more than one source, and in a few cases had conflicting results. Therefore, the investigator assessed strength of evidence for the identified environmental variables in terms of overall support based upon applicable studies. Once the relative evidentiary strengths were assessed, the investigator re-conceptualized these relevant variables into spatially- oriented design domains developed with designers' input as to their work and decision processes. Typical phases in the building design process have been described elsewhere [62].

Through this work, the investigator considered the core principles established, and when empirical research did not definitively or specifically inform needed design knowledge, design best practice and theory-based pathways to impact were also considered as testable hypotheses. (Figure 1.2).

Figure 1.2. Transdisciplinary Iterative Process Diagram. In coordination with a transdisciplinary team, the investigator reviewed and analyzed literature on the school environment and physical activity to identify research findings and strength of evidence. These findings were then synthesized and translated into a set of design guidelines including spatially-oriented domains and strategies, drawing from best practice and theory where there were gaps in the empirical literature. The guidelines are intended to inform both current practice and collaborative research opportunities that will improve the evidence base.



There were no human subjects in this research. Photographs included as illustrations were previously taken by others, are used with their permission, and have been altered to protect all individual identities.

RESULTS

Findings from Literature

A 2012 systematic review of literature pertaining to associations between school built environments and the outcome of childhood overweight and obesity (measured as BMI-percentile weight status categories) found very few studies and determined that results were generally inconclusive [66]. There was considerably more literature pertaining to more proximal PA-related outcomes and the school built environment.

There are many evidence-based PA programs, and such programming in schools has produced increases in children's time spent in MVPA [59,67], although evidence of impact on weight status remains less clear [68,69]. For the most part, PA program evaluations have not addressed physical school environment variables, but they generally support the need for adequate school physical education facilities for in-school and after-school programming, as well as classrooms and other school spaces that can accommodate ample activity and movement among students throughout class time and breaks. In addition, a number of studies have shown that children who walked or cycled to school were more physically active than those who did not actively commute [70-72], and that within-subject time spent in MVPA increased substantially with walking to and from school vs. automobile transport [73]. Children's independent mobility [74] and active commuting to school have decreased dramatically over past decades [75], and much attention has been paid to active commuting to school as a strategy to increase children's overall PA levels. Unfortunately, many school and surrounding neighborhood environments have not been conducive to active commuting [76].

Although many of the reviewed studies identified social facilitators and barriers to PA, in addition to physical environment PA correlates, the intentional focus of this review was the physical 'designed' environment. It should be noted, though, that in the context of this literature, physical environment impacts on relevant social constructs are both theoretically plausible and likely, and social forces can potentially reinforce or diminish physical environment influences. As examples, teacher presence on playgrounds [77], activity supervision [78], and staff training [79] have been associated with higher MVPA among students, along with various types of fixed and unfixed PA equipment. Here, the specific relationships between equipment and social support were not delineated, but there was indication that teachers reinforced PA opportunities created by elements of the physical environment.

The comprehensive review identified 77 empirical studies and literature reviews that addressed aspect(s) related to school built environment design and students' PA. This group of literature addressed a broad array of macro- to micro-level school environment characteristics and their relationships to a range of student PA-related measures. For the most part, based upon accepted epidemiological standards, this work has not demonstrated definitive causal associations between school physical environment characteristics and children's PA. Studies of the impact of environmental settings on human outcomes have presented challenges in control of confounding variables, such as self-selection and spillover effects [80], and it is generally not possible to randomize people to settings such as communities and schools [81]. However, a few studies have used cluster randomized, controlled designs as an achievable alternative to the individual-level randomized controlled trial (RCT).

The final set literature informing the design guidelines consisted of 57 (74.0%) cross-sectional studies, 14 (18.2%) longitudinal study designs, and 6 (7.8%) reviews. Of the cross-sectional studies, 54 were quantitative, 1 used mixed methods, and 2 were solely qualitative. One of the qualitative articles was a report of researchers' observations while conducting a quantitative study rather than a rigorous qualitative design. The mixed methods study and 46 quantitative cross-sectional studies explored potential built environmental correlates of PA. Of the cross-sectional studies, 5 explored the impact of physical environment interventions by comparing different samples at 2 or more points in time. Cross-sectional study sample sizes ranged from 47 to 22,117 individuals. Of the intervention studies with longitudinal measures, 4 were cluster randomized controlled trials, 4 were cluster matched controlled trials, 1 was an individually matched trial, and 5 consisted of within-subject comparisons without randomization or a longitudinal control group. Longitudinal study sample sizes ranged from 9 to 1,465 individuals.

Both independent variable and explanatory built environmental variable definitions and measures varied widely across these studies, precluding opportunities for meta-analyses. PA measures were objectively measured with an instrument or a validated direct observation method in 33 studies, and were self- or parent-reported in 24 studies. Among the 25 studies with instrument measures, devices included several types of accelerometers, energy expenditure-measuring armbands, heart rate telemeters, GPS, infrared imagery, and pedometers. Some studies converted raw observed or instrument measures to clinically-relevant MVPA, and some did not. Even among studies using accelerometers, there were variations in the outcome measures analyzed, including activity counts per time unit, time spent in MVPA or MET-weighted MVPA (MW-MVPA) and other PA intensity levels, and vector magnitude. Other studies measured counts of active users at specified times in defined locations, or assessed proxy reported travel data. Table 1.1 includes a summary of empirical and review literature informing the Physical Activity Design Guidelines for School Architecture, including study design and approach, main findings, and strength of evidence.

Table 1.1. Summaries of Literature.

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
92	Anthamatten et al. 2011	An assessment of schoolyard renovation strategies to encourage children's physical activity	Cross-sectional	Students (n=2,718) age 6-11 at 9 Denver-area schools in underserved neighborhoods (total school enrollment N=3,688)	School-level comparison of utilization and physical activity at Learning Landscapes schoolyards, recently constructed and with older construction, and unrenovated schoolyards. Learning Landscapes schoolyards included gateways, shade structures, gardens, student and public art	Number of users, percentage of children engaged in MVPA (SOPLAY)	Utilization of Learning Landscapes schoolyards was greater than other schools; greatest difference between newly constructed and unrenovated schoolyards. No significant differences in MVPA between schoolyards. Boys exhibited greater utilization and more vigorous PA in schoolyards overall, compared to girls	Moderate
127	Babey et al. 2009	Sociodemographic, family, and environmental factors associated with active commuting to school among US adolescents	Cross-sectional	Youth (n=3,451) age 12-17 across California	Analysis of data from the 2005 California Health Interview Survey to explore associations between socio-demographic, family, and environmental factors and active commuting to school	Active commuting category, numerous socio-demographic, family, and environmental measures	Odds of active commuting to school were higher for those living in urban areas, living closer to school, males, Latinos, from lower-income families, attending public school, without an adult present at home after school, and with parents who knew little about their whereabouts after school	Moderate
142	Benden et al. 2011	The impact of stand-biased desks in classrooms on calorie expenditure in children	Cluster RCT	Students (n=58) in 4 1st grade classrooms at 1 ethnically diverse rural Texas school	Random assignment of classrooms to treatment and comparison scenarios for comparison; treatment classrooms received stand-biased desks; 2 5-day intervals of measurement at pre-and post-intervention time points	Body-Bugg armband-measured caloric expenditure	Treatment group experienced significant increases in caloric expenditure during class time vs. the comparison group	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
143	Benden et al. 2012	Within-subjects analysis of the effects of a stand-biased classroom intervention on energy expenditure	Longitudinal within-subject, pre/post intervention	Students (n=9) age 6-8 at 1 rural Texas elementary school	2 consecutive 5-month trials, one in the fall in a classroom with traditional desks, and one in the spring after the entire classroom had been equipped with stand-biased desks; analysis of within-subject differences pre- and post-intervention	Body-Bugg armband-measured caloric expenditure, steps per minute, teacher-reported observed behaviors	Within-subject energy expenditure increased significantly in the intervention scenario with stand-biased desks Teachers reported an increase in positive in-class behavior and focus on school activities in the intervention scenario	Moderate
144	Blake et al. 2012	Using stand/sit workstations in classrooms: Lessons learned from a pilot study in Texas	Cross-sectional qualitative	Parents and teachers (n=unspecified) whose 1st grade students participated in a trial of stand-biased desks in a rural Texas school classroom	Summary of feedback on classroom and behavior observations from parents and teachers, and feedback from students	Observations about desk adjustment, stool use, student conditioning period, and unanticipated effects	Adjustable stand-biased desks, footrests, and stools require more set-up effort than traditional furniture Although students were told they could use stools or stand at their desks, by the fourth intervention week, more than two-thirds of students had stopped using the stool and removed it from their workstations Peer influence played a role in conditioning students to the desks, as it became 'cool' to stand Teachers reported an unanticipated positive effect of the intervention on students' attention and focus	Preliminary

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
123	Boarnet et al. 2005	Evaluation of the California Safe Routes to School legislation: Urban form changes and children's active transportation to school	Cross-sectional	Parents (n=1,244) of students at 10 California schools within ¼ mile of California Safe Routes to School (SR2S) sites	Analysis of survey data to examine urban form changes, such as installation or widening of bicycle lanes, sidewalks, and crosswalks from SR2S projects, and children's active transportation to school; comparison of survey responses in 2 groups, parents of children who passed SR2S project on usual route to school, and those whose children did not pass SR2S site; inclusion of retrospective questions to assess change	Retrospective and current parent-reported active commuting to school	Based on parent responses, children who passed SR2S projects on their usual routes to school were more likely to have increased their active travel to school than those who did not pass a SR2S site	Moderate
106	Boldemann et al. 2006	Impact of preschool environment upon children's physical activity and sun exposure	Cross-sectional	Students (n=197) age 4-6 at 11 preschools in Stockholm, Sweden	Data collection via environmental assessment, parent questionnaire, staff questionnaire (validity and reliability confirmed), and school-time PA measures of children; analysis of associations between environmental variables and children's PA and UV exposure	Child BMI, environmental factors, pedometer-measured steps, dosimeter-measured UV radiation	Children's mean step count was higher in environments with trees, shrubbery, and broken ground, vs. delimited environments with little vegetation UV exposure was lower in environments with trees, shrubbery, and broken ground No differences between girls and boys	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
157	Boutelle et al. 2004	Using signs, artwork, and music to promote stair use in a public building	Cross-sectional	Users of 1 university building	Independent cross-sectional design with pre- and post-intervention data collection Intervention 1: Signs with health message Intervention 2: Addition of music and artwork	Percentage of individuals using stairs vs. elevators	Increased stair use with music-artwork intervention No increase in stair use with sign intervention only	Preliminary
128	Braza et al. 2004	Neighborhood design and rates of walking and biking to elementary school in 34 California communities	Cross-sectional	Students (n=2,993) age 9-11 from 105 5th grade classrooms at 34 California public elementary schools	Based on teacher-collected student survey data, U.S. Census data, and California Department of Education data, evaluated the relationships between neighborhood design and rates of student walking and cycling to school	Neighborhood-level measures including density, street network connectivity; School-level measures including school size/enrollment, proportion of students walking or cycling to school	Higher population density and larger school size associated with higher walking and cycling rates, controlling for confounders Pairwise correlation between number of intersections per street mile and walking/cycling rates did not hold in regression modeling	Moderate
93	Brink et al. 2010	Influence of schoolyard renovations on children's physical activity: The Learning Landscapes program	Cross-sectional	Students (n=2,718) age 6-11 at 9 Denver-area schools in underserved neighborhoods (total school enrollment N=3,688)	Independent cross-sectional comparison of student physical activity at different types of schoolyards, and in different schoolyard surface conditions	Type of schoolyard, schoolyard surface condition, student time in sedentary, moderate, and vigorous PA (SOPLAY), student energy expenditure (SOPLAY calculation)	Utilization of Learning Landscapes schoolyards was greater than comparison schools Energy expenditure per scan (school level) higher at Learning Landscapes schools vs. comparison schools Boys' and girls' activity rates greater on soft surfaced, structured areas at Learning Landscapes vs. control schools Boys' activity rates greater on hard surface unstructured areas at Learning Landscapes vs. control schools	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
75	Buliung et al. 2009	Active school transportation in the greater Toronto area	Cross-sectional	Independent population samples (n=2,393-10,670) from the Toronto metropolitan area, at time points between 1986 and 2006	Analysis of temporal and spatial trends in students active transportation to school	Urban vs. suburban neighborhood, Proportion of active transportation to school at time points, Children's age groups	Between 1986 and 2006, walking proportion of school trips declined significantly for both 11-13 year olds and 14-15 year olds In 2006, 11-13 year olds walked to school less in the suburbs than in urban Toronto In 2006, 14-15 year olds walked less, but used public transit more, in urban Toronto vs. the suburbs	Moderate
141	Cardon et al. 2004	Sitting habits in elementary school children: A traditional vs. a "moving" school	Cross-sectional	Students (n=47) age 8 at 2 schools: a 'moving school' in Germany, a traditional school in Belgium	Comparison of physical activity and posture between students in 'moving' and traditional school groups Moving school included dynamic furniture and integration of movement in classroom lessons	Accelerometer-measured PA as steps per minute, postural measures, duration and frequency of sitting	Students at the moving school sat statically less, walked around more, exhibited better posture, had lower prevalence of back pain, and had higher PA levels	Moderate
85	Cardon et al. 2009	Promoting physical activity at the pre-school playground: The effects of providing markings and play equipment	Cluster RCT	Students (n=583) age 4-5 at a convenience sample of 40 Belgian public schools	Random assignment of schools to 4 conditions: (1) provision of play equipment, (2) markings painted on playgrounds, (3) provision of play equipment plus markings painted, (4) no change/control; Data collection at pre-and post-intervention time points	Accelerometer-measured activity levels, recess time in MVPA and sedentary behavior	No significant impact of playground interventions on either recess sedentary time or time in MVPA	Strong

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
137	Cohen et. al 2006	Proximity to school and physical activity among middle school girls: the Trial of Activity for Adolescent Girls Study	Cross-sectional	Female students (n=1,554) in middle school enrolled in the multi-state TAAG study	Examination of relationship between distance to school and PA among girls, controlling for potential confounders	Shortest distance between home and school along street network, accelerometer-measured MET-weight MVPA	Distance to school was inversely associated with MET-weight MVPA For each incremental mile from school, girls engaged in an average of 13 fewer MET-weighted minutes per week	Moderate
96	Cohen et al. 2008	School design and physical activity among middle school girls	Cross-sectional	Female students (n=1,566) in middle school who were enrolled in the multi-state Trial of Activity for Adolescent Girls (TAAG)	Cross-sectional analysis of school environment factor associations with levels of PA	Size of school building footprint and school grounds, count of active outdoor amenities, in-school accelerometer-measured MET-weight MVPA and light PA	Number of outdoor PA facilities was positively associated with MVPA, but mediated by weather Outdoor field size was not associated with PA	
90	Colabianchi et al. 2009	Utilization and physical activity levels at renovated and unrenovated school playgrounds	Cross-sectional	Users of 20 school playgrounds (10 renovated and 10 unrenovated) in Cleveland	School-level analysis of usage and PA at renovated vs. unrenovated playgrounds, schools matched on school and neighborhood characteristics, children observed outside of school hours	Usage of playground, proportion of children engaged in MVPA on the playground (SOPLAY)	Higher overall utilization of renovated vs. unrenovated playgrounds No significant difference between proportion of time spent in MVPA at renovated vs. unrenovated playgrounds	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
91	Colabianchi et al. 2011	Features and amenities of school playgrounds: A direct observation study of utilization and physical activity levels outside of school time	Cross-sectional	Users of 20 school playgrounds (10 renovated and 10 unrenovated) in Cleveland	School-level analysis of usage and PA at renovated vs. unrenovated playgrounds, schools matched on school and neighborhood characteristics, children observed outside of school hours, analysis of associations with a playground attributes	Usage of playground, proportion of children engaged in MVPA (SOPLAY), playground attributes from the Environmental Assessment of Public Recreation Spaces assessment tool	At renovated playgrounds, total number of play features positively associated with utilization among adults and girls Lower cleanliness was associated with lower usage among boys and girls Coverage and shade for resting features positively associated with utilization among boys No significant associations between playground attributes and proportion of active children	Moderate
154	Community Preventive Services Task Force 2010	Recommendations for use of point of decision prompts to increase stair use in communities	Review	Published studies addressing use of stair point-of-decision prompts	Systematic review of research addressing the impact of point-of-decision prompts for stair use	N/A	Stair point-of-decision prompts may increase stair use Insufficient evidence to show effectiveness of stairwell enhancements with point-of-decision prompts	Moderate
109	Cradock et al. 2007	Characteristics of school campuses and physical activity among youth	Cross-sectional	Students (n=248) in 10 middle schools in the Boston area	Associational analysis of school characteristics from site data collection and secondary data sources in 2004-5, and student physical activity data collected in 1997 for RCT of a school-based intervention	Accelerometer-measured vector magnitude, school characteristics including campus area, play area, and building area per student	Larger school campus area per student, building area per student, and play area per student were positively associated with PA Mean vector magnitude differences translated to walking 2 additional miles over a week's time	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
138	D'Haese et al. 2011	Criterion distances and environmental correlates of active commuting to school in children	Cross-sectional	Parents (n=696) or 6th grade students in 44 randomly selected classes at Belgian elementary schools	Analysis to determine home to school criterion distances at which at least 85% of active school commuters lived Subsequent analysis to identify correlates of active commuting within these distances	Neighborhood Environment Walkability Scale for Youth (NEWS-Y) subscales, parent-reported child active commuting to school, distance from home to school	59.3% of total sample actively commuted to school Criterion distances set at 1.5 kilmeters for walking and 3.0 kilometers for cycling At home to school distance of 2.01-2.50 kilometers, number of passive commuters exceeded active commuters Among active commuters, longer distance to school associated with more cycling vs. walking	Moderate
2	Dordel and Breithecker 2003	Bewegte Schule als Chance einer Förderung der Lern- und Leistungsfähigkeit	Cluster matched controlled trial	Students (n= 56) in 3rd grade from 3 classrooms at a German elementary school	Compared students' concentration at 3 times during the school day based on 3 levels of school-based environment-influenced PA: (A) typical class and school environment; (B) class with space and encouragement to do moving activities and a schoolyard with features to inspire exertion; (C) class that included an active learning pedagogy, a dynamic sitting and flexible furniture environment, and a schoolyard like group B	Concentration performance measured via attention stress-test	Academic performance in the class with moving activities and active schoolyard (B) was better than in the typical class and school environment (A) during the school morning Academic performance in the classroom with ergonomic furniture, moving activities, and active schoolyard (C) were significantly better than both (A) and (B) Group (A) in the typical school environment recorded a significant decline in academic performance at later times of day	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
57	Durant et al. 2009	Relation of school environment and policy to adolescent physical activity	Cross-sectional	Students (n=165) age 18 in 3 U.S. cities	Analysis of survey data for associations between PA and several school environment variables	Self-reported PA, school PA equipment accessibility, field access, after-school supervised PA, days of PE class per week	Access to school fields after school, and days of PE per week positively correlated with overall PA PA equipment and after-school supervised PA not associated with overall PA	Moderate
104	Dyment and Bell 2007	Active by design: Promoting physical activity through school ground greening	Cross-sectional	Teachers, parents, and administrators (n=105) associated with 59 Canadian schools that had "greened" the school site	Used data from a prior national survey Analyzed participants' perspectives as to the impact of school culture and grounds characteristics on students' PA (content validity confirmed)	Percentages of participants designating design and culture factors of school grounds as encouraging or discouraging PA	Adequate space, diverse play opportunities, and interaction with natural elements deemed important in stimulating active play Children were perceived to be more active with opportunities for garden or green space care, and when rules and supervision allow open-ended play	Moderate
105	Dyment and Bell 2008	Grounds for movement: Green school grounds as sites for promoting physical activity	Cross-sectional	Teachers, parents, and administrators (n=105) associated with 59 Canadian schools that had "greened" the school site	Used data from a prior national survey Analyzed participants' perspectives as to the impact of school culture and grounds characteristics on students' PA (content validity confirmed)	Participant impressions of impact of school ground greening on children's PA	School ground greening seen as diversifying children's play repertoire, inviting children to jump, climb, dig, lift, role play, etc., and potentially encouraging children's PA by increasing non-competitive and open-ended play at school	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
125	Eyler et al. 2008	Policies related to active transport to and from school	Cross-sectional qualitative	Adult stakeholders (n=69), including teachers, principals, parents, local community organizers, school and city officials, and public safety representatives, at 9 elementary schools in 7 states	Qualitative analysis of school stakeholder interview data regarding school-related policies and student active transport to school	Explored potential factors and policies related to students	Identified 2 distinct aspects of school policies related to active transport to school: (1) influential factors, and (2) policy actions Influential factors included sidewalks, crosswalks and crossing guards, personal safety concerns, advocacy group involvement Policy actions included school speed zones, drop-off and no transport zones, school siting, school start and dismissal time	Moderate
86	Farley et al. 2007	Safe play spaces to promote physical activity in inner-city children: Results from a pilot study of an environmental intervention	Cluster matched controlled trial	Children (n=710) using 2 school playgrounds after school hours in New Orleans; students (n=465) in grades 2-5 at participating schools	Direct observation of school playground use and PA over time in an intervention school with an open playground and attendants, vs. a comparison school site, survey of sedentary time	Direct observation usage counts, and PA levels using (modification of SOPLAY), sedentary time per school-based survey	Number of children outdoors and physically active was higher in the intervention neighborhood, and there were concomitant declines in reported sedentary indoor activities	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
102	Fein et al. 2004	Perceived environment and physical activity in youth	Cross-sectional	Students (n=610) in grades 9-12 at 4 rural Canadian high schools	Based on self-report questionnaire, analysis of associations between perceived availability and importance of physical environment resources, and PA	Perceived physical environment resources availability, Perceived physical environment resources importance, self-reported PA	Perceived higher importance of the school environment PA resources (e.g., gym space allows me to do activities, sport/exercise equipment works well, school athletic facilities are accessible, etc.) was associated with PA	Moderate
110	Fernandes et al. 2010	Facility provision in elementary schools: Correlates with physical education, recess, and obesity	Cross-sectional	Students (n=8,935) in 5th grade at schools across the U.S, with oversampling of racial/ethic minorities and attendees of private schools	Analysis of associations between demographic and location variables, and availability and adequacy of gymnasium and playground; analysis of associations between facility and location characteristics, and physical education and recess time; used data from the Early Childhood Longitudinal Survey Kindergarten Cohort	Multiple variables including child weight status, degree of urbanization, climate zone, availability and adequacy of gymnasium, availability of adequate playground, physical education time, recess time	Students from underserved backgrounds more likely to attend a school with poorer gymnasium and playground provision Gymnasium availability associated with additional 8.3 minutes of PE per week, and additional 25 minutes in humid climate zones No significant results of playground and gymnasium adequacy in relation to PE and recess time, or in relation to obesity trajectory	Moderate
139	Fitzhugh et al. 2010	Urban trails and physical activity: A natural experiment	Longitudinal pre/post intervention with comparison group	Children, adolescents, and adults living in 3 Knoxville, Tennessee neighborhoods	Comparison of changes over 2 years in physical activity in the intervention neighborhood that was retrofitted with an urban trail, and in 2 comparison neighborhoods	Counts of directly observed PA, Counts of active transport to school	Counts of physical activity increased in the intervention neighborhood retrofitted with an urban trail, and decreased in the comparison neighborhood No intervention effect on counts of active commuting to school	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
95	Fjørtoft et al. 2010	Schoolyard physical activity in 14-year-old adolescents assessed by mobile GPS and heart rate monitoring analysed by GIS	Cross-sectional	Students (n=81) age 14, in 9th grade at 2 Norwegian schools	Spatial tracking of children's movements and monitoring of heart rates during outdoor activities at school lunch break over a several day period; mapping of average heart rates to spatial grids with conversion to GIS wire graphs; confirmation that BMI of sample was comparable to national data	Students' chest belt-measured heart rate, recorded via GPS device; students' GPS-measured movements; proportion of time spent in LPA, MVPA, VPA, per heart rate conversion	At both schools, 70% of students' break time was allocated to low levels of PA Highest levels of PA occurred at a handball goal area, with higher intensity in girls vs. boys	Moderate
153	Ford and Torok 2008	Motivational signage increases physical activity on a college campus	Cross-sectional with intervention	Users of 1 college campus building	Independent cross-sectional analysis to compare stair use before and after signage intervention	Stair use at baseline, with motivational signage intervention, and after signage removed	Motivational signs significantly increased stair use, which was maintained one week after signs were removed	Preliminary
65	Garcia et al. 2014	Comparison of stable and dynamic school furniture on physical activity and learning in children	Longitudinal within-subject, 2 exposures	Students (n=12) in 1st-6th grade at a rural Virginia primary and elementary school	Children participated in 2 conditions, stable vs. dynamic furniture, presented in balanced order; within-subject analysis of differences in PA, energy expenditure, and learning between the two conditions	Accelerometer-measured activity counts, indirect calorimetry device-measured energy expenditure, answers to questions on a brief lecture and age-appropriate math problems	Average activity counts greater in the dynamic vs. stable furniture condition No significant differences in energy expenditure or percentage of questions and problems answered correctly 75% of participants reported a preference for sitting in the dynamic vs. stable furniture	Preliminary

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
132	Giles-Corti et al. 2011	School site and the potential to walk to school: The impact of street connectivity and traffic exposure in school neighborhoods	Cross-sectional	Students (n=1,480) in school years 5-7 and their parents (n=1,332) at 25 Australian primary schools	Analysis of associations of children walking to school with neighborhood walkability, based on street connectivity and traffic exposure, within 2 km of schools	School-specific walkability index, pedshed (ratio of pedestrian network area to total area), vehicular traffic exposure, measured weight status, frequency of walking to school	Regular walking to school was greater in high walkable neighborhoods with high street connectivity and low traffic volumes Regular walking to school was less likely in neighborhoods with high connectivity and high traffic	Moderate
130	Harrison et al. 2011	Environmental correlates of adiposity in 9-10 year old children: Considering home and school neighbourhoods and routes to school	Cross-sectional	Children (n=1,995) age 9-10 in the UK	Analysis of data from the SPEEDY (Sport, Physical activity and Eating behavior: Environmental Determinants in Young people) to investigate environmental correlates of weight status in the home neighborhood, school neighborhood, and modeled route between home and school	Fat mass index (FMI), characteristics of areas around homes, schools, and routes to school	Among girls, higher proportion of accessible open land and lower mix of land uses around school associated with higher FMI Among active traveler boys, major roads in school area associated with lower FMI Among non-active traveler boys, presence of major roads in home neighborhood associated with higher FMI No associations between FMI and route characteristics	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
94	Haug et al. 2010	The characteristics of the outdoor school environment associated with physical activity	Cross-sectional	Students (n=16,471) in primary grades 4-7, and secondary grades 8-10 at Norwegian schools	Analysis of associations in data collected via self-administered questionnaires	School physical environment characteristics, daily physical activity during school breaks	At secondary level: Boys and girls had higher odds of being physically active at schools with larger number of outdoor facilities, and at schools with a sledding hill vs. those without Boys had higher odds of being physically active at schools with hopscotch/skipping rope areas, at schools with soccer fields, at schools with playground equipment No significant results at primary level	Moderate
122	Heinrich et al. 2011	Hawai'i's opportunity for active living advancement (HO'ĀLA): Addressing childhood obesity through Safe Routes to School	Cross-sectional	Parents (n=1,648) of children in 1st and 4th grades from 13 schools in under-resourced communities in Hawai'i	Report of baseline measures for a planned longitudinal study of Safe Routes to School (SR2S) and active commuting and PA; descriptive analysis of parent survey, data from PATH Hawai'i SR2S Toolkit and Pedestrian Environment Data Scan	Parent-reported travel modes to and from school, Distance from home to school, Traffic counts and safety on routes, Physical condition of street segments on routes	Among the 5 schools in neighborhoods and 8 in rural settings, few children walked or biked to school, and most were driven to and from school by parents	Preliminary

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
111	Hobin et al. 2010	A multilevel examination of factors of the school environment and time spent in moderate to vigorous physical activity among a sample of secondary school students in grades 9-12 in Ontario, CA	Cross-sectional	Students (n=22,117) in grades 9-12 at 72 Ontario secondary schools	Analysis of associations between student and environment characteristics and student PA, based on student survey and GIS data	Environment- and student-level characteristics, student self-reported time spent in MVPA	School level differences accounted for 3% of the variability in student MVPA; Students of schools with daily PE or provision of alternate room for physical activity spent more time in MVPA than students at schools lacking these resources; As school neighborhood walkability and land-use mix increased, student time spent in MVPA decreased	Moderate
79	Huberty et al. 2011	Environmental modifications to increase physical activity during recess	Cross-sectional	Students (n=237) in 3rd-6th grade at 4 schools in a Midwestern metropolitan area	One school assigned to each of the following scenarios: (1) Provision of recreational equipment and staff training, (2) Provision of recreational equipment, (3) Provision of staff training, (4) Control/no training or equipment provided Analysis of associations between scenarios and MVPA outcomes	Accelerometer-measured PA, weight status	Compared with the control, healthy weight boys with equipment and staff training had more MVPA (greatest difference), overweight and obese boys with staff training had more MVPA, overweight and obese girls with equipment and staff training had more MVPA, and healthy weight girls with equipment exhibited less MVPA	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
136	Kerr et al. 2006	Active commuting to school: Associations with environment and parental concerns	Cross-sectional	Parents (n=259) of children age 5-18, randomly selected from neighborhoods chosen for variability in neighborhood characteristics and income in Seattle, WA	Analysis of questionnaire data to explore relationships of objective and perceived neighborhood environment characteristics, parent concerns about children's active commuting to school, with the outcome of active commuting to school	Perceived neighborhood characteristics, GIS- and Census-measured neighborhood characteristics, Parent-reported frequency of child's active commuting, parental concern scale	Parental concern inversely associated with students' active commuting Among high-income neighborhoods, more active commuting in higher vs. lower walkability neighborhoods Among low-income neighborhoods, no difference in active commuting based on neighborhood walkability Neighborhood aesthetics independently associated with active commuting	Moderate
140	Lanningham-Foster et al. 2008	Changing the school environment to increase physical activity in children	Longitudinal within-subject, 3 exposures	Students (n=40) in 4th-5th grades at a Rochester, MN elementary school	Comparison of students' PA in 3 school environments: traditional school with chairs and desks, activity-permissive open environment called "The Neighborhood," traditional school with desks that encouraged standing; cross-sectional comparison with age-matched group on summer vacation	Accelerometer-measured physical activity	PA levels of children while attending school at 'The Neighborhood" were higher than in both the traditional and stand-biased classroom, and were equivalent to activity levels of the group on summer vacation	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
151	Lee et al. 2012	Promoting routine stair use: Evaluating the impact of a stair prompt across buildings	Cross-sectional with intervention	Users of 3 New York City buildings: a 3-story health clinic, an 8-story academic building, and a 10-story housing structure	Independent cross-sectional analysis to compare stair use before and after posting of prompt stating, “Burn Calories, Not Electricity”; measure pre- and immediately post-intervention, with 9 month follow-up at 2 sites	Ascending and descending stair and elevator trips	Increased stair use at all sites after posting of prompt Relative increases in stair use maintained at the 2 sites with 9 month follow-up	Moderate
152	Lewis and Eves 2012	Prompt before the choice is made: Effects of a stair-climbing intervention in university buildings	Cross-sectional with intervention	Users of 4 university buildings	Independent cross-sectional analysis to compare impact of interventions: (1) Motivational signage in elevator, (2) Point-of-choice prompt	Counts of stair users	No effect of motivational signage Stair climbing increase with the point-of-choice prompt	Moderate
129	Loucaides 2009	School location and gender differences in person, social, and environmental correlates of physical activity in Cypriot middle school children	Cross-sectional	Students (n=676) at middle schools in Cyprus	Exploration of possible associations of personal, social, and environmental factors with PA, with intent to understand why obesity and overweight status more prevalent in rural areas	Urban vs. rural school location, numerous personal, social, and environmental factors	Significant interaction effects of female gender and rural location on weekly frequency parent transports child, and lower weekly frequency of sports club attendance Boys reported play outside more hours per day than girls	Moderate
148	Ludwig and Breithecker 2008	Untersuchung zur Änderung der Oberkörperdurchblutung während des Sitzens auf Stühlen mit beweglicher Sitzfläche	Matched controlled trial	Male students (n=10) age 14, in 8th grade at a German school	Comparison of students’ thermal body temperatures, one group using traditional rigid seating and one group using dynamic seating	Trunk body temperature measured by infrared imagery and software thermography	Higher body temperature over 3 school hours in dynamic vs. static seating	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
108	Martin et al. 2012	School and individual-level characteristics are associated with children's moderate to vigorous intensity physical activity during school recess	Cross-sectional	Students (n=408) in 6th grade at 27 Austrialian primary schools	Analysis of associations between children's recess MVPA and child, school, policy, and socio-cultural factors	Accelerometer-measured PA, multiple individual and environmental factors	Higher daily recess MVPA was associated with newer schools, schools with a higher number of grassed surfaces per child and fewer shaded grass surfaces, and schools with a PE coordinator meeting Australian guidelines	Moderate
97	Millstein et al. 2011	Home, school, and neighborhood environment factors and youth physical activity	Cross-sectional	Youth (n=137) age 12-18, and parents (n=104) of children aged 5-11, from San Diego, Boston, and Cincinnati areas	Analysis of associations between environment factors and youth PA, based upon survey data (test-retest reliability confirmed)	Self- or parent-reported PA, Home, Proxy-reported travel information, School and neighborhood environment factors	Count of school PA equipment positively associated with adolescent PA, but not PA of younger children Some home and neighborhood characteristics associated with PA for children and/or adolescents	Moderate
126	Mitra et al. 2010	Spatial clustering and the temporal mobility of walking school trips in the greater Toronto area, Canada	Cross-sectional	Households with 11-13 years olds in the Greater Toronto Area (817,000 trip records)	Analysis of travel data from the Transportation Tomorrow Survey, and urban area classification, based upon spatial and temporal (AM vs. PM) clustering	Spatial and temporal clustering of trips, Urban area classification	Higher spatial clustering of walking in the urban and inner-suburban areas, and in low household income areas Temporal clustering of walking less likely in inner-suburban and outer-suburban than in urban areas	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
107	Nicaise et al. 2012	Evaluation of a redesigned outdoor space on preschool children's physical activity during recess	Cross-sectional with intervention	Students (n=107) age 4-5 at a university preschool	Collection of data from 2 independent samples at baseline, and several months after an outdoor space redesign intervention; renovation based on urban naturalism concepts, with plantings and land contours intended to promote discovery and social interaction, and including a looping path, addition of a grassy hill, and removal of 2 play structures to create more open space	Accelerometer-measured PA, ObservationPA (OSRAC-P)	Based on observational data, fewer intervals spent sedentary and more intervals in light PA in the intervention scenario vs. the baseline scenario Higher odds of observed MVPA with the new looping cycle path, increased playground open space, and the new grass hill No significant results based on accelerometry data	Moderate
149	Nicoll et al. 2007	Spatial measures associated with stair use	Cross-sectional	Users of 10 buildings on 2 university campuses	Analysis of associations between stair use and spatial variables	Stair use measured with infrared monitors, spatial measures, appeal, convenience, comfort, legibility, and safety of stairs	Stair use was associated with shorter travel distance to entrance, higher area and accessibility of stair, area of visual field from stair, fewer turns required from stair to entrance, and most integrated path to stair No significant association of stair use with appeal, comfort, or safety	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
89	Nielsen et al. 2010	Permanent play facilities in school playgrounds as a determinant of children's activity	Cross-sectional	Students (n=417) age 5-12 at 7 schools in semirural New Zealand communities	Analysis of association between school permanent play facilities and student PA; permanent play facilities defined as physical structures on the school grounds, excluding buildings, used by children for play and/or sports activities, e.g., swings, slides, clusters of trees, playground markings, goals and hoops for ball activities, etc.	Number of permanent play facilities at schools, accelerometer-measured activity counts and MVPA in and outside of school	Number of permanent play facilities in schools ranged from 14 to 35, and was positively associated with PA With additional permanent play facilities, average accelerometer counts increased both in school and overall Each additional play facility associated with more time in MVPA both in school and overall	Moderate
155	Nocon et al. 2010	Increasing physical activity with point-of-choice prompt: A systematic review	Review	Studies (n=25)	Systematic literature review	N/A	Point-of-choice stair prompts increased rate of stair climbing in escalator settings, but not definitively in elevator settings	Moderate
88	Ozer 2007	The effects of school gardens on students and schools: Conceptualization and considerations for maximizing healthy development	Review	Studies (n=5)	Literature review and conceptual framework	N/A	Four studies addressed nutrition or PA outcomes, deemed promising but overall inconclusive Proposed a conceptual framework for potential impacts of school gardens	Preliminary

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
133	Panter et al. 2010	Attitudes, social support and environmental perceptions as predictors of active commuting behavior in school children	Cross-sectional	Parents/guardians and children (n=2,012) age 9-10 in urban areas, towns, and villages in Norfolk, England	Based on data from the SPEEDY (Sport, Physical activity and Eating behavior: Environmental Determinants in Young people), analysis of associations between active commuting behavior and potential correlates	Active commuting behavior, Child BMI, Attidudinal and social support factors, Neighborhood and route environment characteristics	40% of children usually walked to school, and 9% cycled Positive associations between active commuting to school and parental attitudes, lower safety concerns, social support from parents and friends, parent-reported neighborhood walkability Negative association of distance to school and active commuting moderated by parental attitudes for short distances, and safety for long distances	Moderate
121	Panter et al. 2010	Neighborhood, route, and school environments and children's active commuting	Cross-sectional	Students (n=2,012) age 9-10 at 92 schools in Norfolk county, UK	Associational analysis of active commuting to school with characteristics of neighborhood and route to school, and school environments (assessed via school audit and teacher questionnaires)	Frequency of active commuting to school, GIS measures of neighborhood characteristics and routes to school, School environment factors	Students had lower odds of walking to school with higher directness of route based on route length/direct distance ratio, and lower odds of walking with greater distance Students had higher odds of walking to school with higher road density, and without a main road on the route	Moderate
160	Poole	The place for ubiquitous computing in schools: Lessons learned from a school-based intervention for youth physical activity	Longitudinal pre/post intervention	Students (n=1,465) age 11-13 at 37 Title I U.S. middle schools; Survey sample subset: Students (n=577), parents (n=380), teachers (n=19)	Evaluation of PA impact of the American Horsepower Challenge (AHPC), a pedometer-based health game in a designed virtual reality environment	Pedometer-measured steps/day, Game website usage, Survey-reported PA attitudes, social support	Participants' PA levels increased during the game time period	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
83	Ridgers et al. 2007	Long-term effects of playground markings and physical structures on children's recess physical activity levels	Cluster matched controlled trial	Students (n=470) at 26 elementary schools in deprived areas of a large city in Northwest England	Comparison of PA trends at 15 intervention school playgrounds redesigned with color-coded zones: red for sports, blue for multiple activities, and yellow for quiet play, and physical sports structures and seating were added, vs. 11 comparison schools with no playground intervention	Recess time spent in heart rate telemeter- and accelerometer-measured PA at baseline, 6-week follow-up, and 6-month follow-up	In both the short and longer term, significant positive intervention effects on recess time spent in MVPA and vigorous PA	Strong
103	Ridgers et al. 2012	Physical activity during school recess: A systematic review	Review	Studies (n=53)	Systematic review of 1990-2011 literature pertaining to correlates of students' school recess PA	N/A	44 variables identified across the socio-ecological framework Positive associations of recess PA with overall provision of PA facilities, unfixed equipment, and perceived encouragement of PA	Moderate
150	Ruff et al. 2014	Associations between building design, point-of-decision stair prompts, and stair use in urban worksites	Cross-sectional	Adult (n=1,348) employees of the City of New York	Analysis of associations between stair use and building environment and individual variables	Self-reported stair use, Building assessment data	Stair prompts, naturally lit stairwells and stairwell visibility associated with increased likelihood of stair use Higher floor location, total floors in building, female gender, and higher BMI negatively associated with stair use	Preliminary

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
78	Sallis et al. 2001	The association of school environments with youth physical activity	Cross-sectional	Physical activity areas (n=137) at 24 San Diego public middle schools with mean enrollment of 1,081 students	Area-level analysis of observed students' non-PE PA in defined school areas; modeling of PA associations with and variance explained by environmental variables	Number of participants, students in MVPA (SOPLAY), school environment variables including area type, area size, improvements (e.g., basketball hoops/courts, other sports courts, etc.)	Environmental variables explained 42% of variance in girls' PA, and 59% of variance in boys' PA Improvements and supervision were associated with PA among girls and boys Supervision was more important indoors vs. outdoors Among girls, equipment was associated with higher PA outdoors, but not indoors	Moderate
117	Salmon et al. 2007	Associations among individual, social, and environmental barriers and children's walking or cycling to school	Cross-sectional	Parents (n=720) children age 4-13 from capital cities in Australia	Recruitment of parents via random-digit dialing; analysis of associations between potential influential variables and the outcome of children walking or cycling to school	Parent-reported child frequency of walking or cycling to school, Individual, social, and environmental variables	41% of children walked or cycled to school 1 or more times per week Significant environmental barriers were "too far to walk" and "no direct route" Individual barriers such as "no time in the mornings", and social barriers such as "no other children to walk with" also significant	Moderate
87	Scott et al. 2007	Comparing perceived and objectively measured access to recreational facilities as predictors of physical activity in adolescent girls	Cross-sectional	Female students (n=1,367) in middle school enrolled in the multi-state TAAG study		Accelerometer-measured MW-MVPA, Number of objectively measured neighborhood PA facilities, Number of perceived neighborhood PA facilities, Perceived accessibility of PA facilities	Number of neighborhood PA facilities strongly associated with MVPA Perceptions of number of facilities associate with PA For each additional PA facility perceived, there was 3% more MW-MVPA	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
114	Scott et al. 2007	Weekend schoolyard accessibility, physical activity, and obesity: The Trial of Activity in Adolescent Girls (TAAG) study	Cross-sectional	Female students (n=1,556) in middle school enrolled in the multi-state TAAG study	Analysis of associations between accelerometer-measured PA over one weekend and the number of PA amenities and accessibility in half-mile radii of girls' residences	Accelerometer-measured Met Weight-MVPA, PA facilities and accessibility within defined residential areas, BMI	Number of inaccessible school-based facilities was associated with higher BMI No association of school facility availability and MW-MVPA	Moderate
120	Silva et al. 2011	Active commuting: Prevalence, barriers, and associated variables	Cross-sectional	Students (n=1,672) age 11-17 in Brazil	Analysis of self-reported data from a questionnaire about active commuting to school, PA data from a diary method, and sedentary behaviors, and measured fitness and body composition data	Active or passive per self-reported active commuting to school, Low vs. medium/high energy expenditure based diary PA, Hours/day of TV and computer use, BMI, Cardiovascular fitness, Environmental variables	62.5% of students actively commuted to school Lower prevalence ratio of active commuting among students of private schools and students living further from schools Lower prevalence ratio of active commuting with greater time spent commuting Barriers to active commuting were distance, crime/danger, and traffic No associations identified with body composition variables	Moderate
98	Skala et al. 2012	Environmental characteristics and student physical activity in PE class: Findings from two large urban areas of Texas	Cross-sectional	Students (n=6,740) in 211 3rd, 4th and 5th grade PE classes in 74 Texas public schools	Analysis of associations between environmental characteristics and class-level PA	MVPA (SOFIT), Environmental variables including class size, class time, class location, lesson contexts	All environmental variables positively associated with MVPA, except for teacher gender Children's MVPA negatively associated with class time and class size, and positively associated with outdoor class location and active lesson context	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
82	Stratton and Mullan 2005	The effect of multicolor playground markings on children's physical activity level during recess	Cluster matched controlled trial	Students (n=240) at 8 schools: 2 early primary (student age 4-7) and 2 late primary (student age 7-11) schools in Northeast Wales, and 2 early primary and 2 late primary control schools in Northwest England	Analysis of the impact of multicolor playground markings on student PA based on pre- and post-intervention measures; Welsh schools received playground intervention, and English schools served as controls; schools matched by playground dimensions and student socio-economic status; random selection of participants within school populations	Recess time spent in heart rate telemeter-measured MVPA and vigorous PA	Painting of playground markings in the intervention schools increased time spent in MVPA and vigorous PA, at least in the short term	Strong
124	Timperio et al. 2006	Personal, family, social, and environmental correlates of active commuting to school	Cross-sectional	Parents of students (n=235) age 5-6 and students (n=677) age 10-12 from 19 elementary schools in Melbourne, Australia	Self-administered questionnaires to parents of younger children, and self-administered questionnaires to 10-12 year olds; analysis to identify correlates of active commuting (walking or cycling) to school	Reported frequency of student active commuting to school, weight status, multiple neighborhood and school environment, family, social, and individual potential correlates	In both age groups: negative correlates of active commuting included parental perception of few children in neighborhood, no lights or crossings on route, and a busy road barrier; children more likely to commute actively if route <800 meters Among younger children, a steep incline on the route to school negatively associated with active commuting Among older children, good connectivity on route negatively associated with active commuting No associations between perceived energy levels, enjoyment of PA, family factors, or weight status	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
115	Trilk et al. 2011	Do physical activity facilities near schools affect physical activity in high school girls?	Cross-sectional	Female students (n=1,394) in 12th grade from 22 South Carolina high schools	Investigation of associations between number of PA facilities within walking distance (.75 mile buffer zone) of school, and self-reported PA behavior	PA from 3-Day Physical Activity Recall (3DPAR), GIS-measured distances between school and PA facilities, BMI	Overall, girls who attended schools with ≥5 PA facilities within the school buffer zone reported more daily PA than girls with <5 facilities nearby This finding held for rural schools, but not for girls in urban/suburban schools	Moderate
134	Van Dyck et al. 2009	Lower neighbourhood walkability and longer distance to school are related to physical activity in Belgian adolescents	Cross-sectional	Adolescents (n=60) age 12-18 from 120 randomly-selected addresses in a suburban area with low walkability and from an urban area with high walkability, in Belgium	Comparison of PA and active commuting to school between the more and less walkable neighborhoods	Neighborhood Environment Walkability Scale (NEWS) subscores, pedometer- and activity log-measured PA, distance to school	Suburban students, whose schools were further from home, cycled to school more than urban students No difference in walking to school between suburban and urban students Marginal significance of higher step count per day among suburban vs. urban students	Moderate
101	Van Sluijs et al. 2011	School-level correlates of physical activity intensity in 10-year-old children	Cross-sectional	Students (n=1,908) age 10 at 92 schools in Norfolk, UK	Analysis of associations between school factors and PA intensity based upon a population sample	Accelerometer-measured school-based time in sedentary, moderate, and vigorous PA, 40 school physical and social environment factors	School's number of sports facilities of at least medium quality associated with greater minutes of VPA	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
84	Verstraete et al. 2006	Increasing children's physical activity levels during recess periods in elementary schools: The effects of providing game equipment	Cluster RCT	Students (n=235) at 7 Belgian elementary schools	Random school assignment to intervention and control groups; analysis of the impact of an intervention providing game equipment on students' PA during recess and lunch break	Pre- and post-intervention accelerometer-measured MPA and MVPA	Children's lunch break MVPA and recess MPA increased in the intervention group with game equipment, and decreased in the control group	Strong
118	Voorhees et al. 2010	Neighborhood design and perceptions: Relationship with active commuting	Cross-sectional	Female students (n=890) from the multi-state TAAG study, who lived within 1.5 miles of school	Analysis of self-administered survey data about walking behavior and neighborhood, and objective GIS neighborhood data	Self-reported walking to and from school, Perceived characteristics of neighborhood, Objective characteristics of neighborhood	56% of girls walked to or from school at least 1 day/week Girls were twice as likely to walk to or from school if they perceived their neighborhoods as safe, and perceived that they had places they liked to walk Girls were more likely to walk if they lived closer to school, had more active destinations in the neighborhood, and had smaller-sized blocks White girls walked more frequently than Hispanic or African American girls	Moderate
112	Wechsler et al. 2000	Using the school environment to promote physical activity and healthy eating	Review	Studies (n=15 related to school facilities and PA)	Review of literature on aspects of the school environment and their relations to PA and nutrition behaviors, and environmental change interventions promoting PA	N/A	Access to convenient play spaces and facilities positively correlated with young people's physical activity Access to a variety of PA facilities may be important	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
64	Wells et al. 2014	School gardens and physical activity: A randomized controlled trial of low-income elementary schools	Cluster RCT	Students at 12 New York state elementary schools (survey n=227 across all schools, accelerometry n=124 at 8 schools, direct observation n=117 at 4 schools)	Random assignment of schools to school garden intervention, with 6 control schools waitlisted waitlisted for a garden to be installed after study completion; comparison of school-time PA trends based on measures at baseline, and at 1, 2, and 3 semesters post-intervention, in the 2 scenarios	PA measured by accelerometer, self-report (Girls Health Enrichment Multi-site Study Activity Questionnaire), and direct observation	Self-reported sedentary activity decreased more from baseline to follow-up in the garden schools than in control schools During the school day, accelerometer-measured MVPA increased more from baseline to follow-up in the garden schools than in control schools Based on group-level direct observation, children moved more and sat less in outdoor garden-based lesson vs. indoor classroom-based lesson	Strong
77	Willenberg et al. 2010	Increasing school playground physical activity: A mixed methods study combining environmental measures and children's perspectives	Cross-sectional, mixed methods	Students (n=3,006) at 23 primary schools in low socio-economic areas of Melbourne, Australia	Quantitative analysis of associations between student PA and playground characteristics; qualitative analysis of focus groups at a subset of 12 schools including a concept map, group discussion, drawing, and photographic ordering	MPA and VPA (SOPLAY), Playground characteristic, e.g., hard/soft surface, fields with markings/goals, fixed or loose play equipment, no permanent equipment or markings, teacher supervision in setting	Larger proportions of students in VPA with loose equipment, and with teacher supervision, vs. when those were unavailable Positive associations of fixed play equipment, and hard surfaces with court/play-line markings, with proportion of students in MPA Qualitatively, children identified fixed play equipment and hard-surfaced courts with play-line markings as invitations to active play	Moderate

Ref. #	Author	Title	Study Design	Sample	Approach	Key Measures	Main Findings	Strength of Evidence
135	Zhu and Lee 2008	Walkability and safety around elementary schools: Economic and ethnic disparities	Cross-sectional	Neighborhoods in areas around 73 public elementary schools in Austin, TX	Neighborhood-level analysis of disparities in environmental support for walking near elementary schools, based upon secondary data	Neighborhood-level measures including ethnicity proportions, poverty, walkability, crime, visual quality, maintenance, safety, distances to school	Neighborhoods with higher Hispanic student percentage had greater dangers from traffic and crime, and also higher walkability based upon presence of sidewalks, greater density, and mixed land uses Poor neighborhoods had many adverse street-level conditions, but also shorter distances to school and lower traffic volumes	Moderate
119	Zhu and Lee 2009	Correlates of walking to school and implications for public policies: Survey results from parents of elementary school children in Austin, Texas	Cross-sectional	Parents/guardians (n=2,695) of students from 19 elementary schools in Austin, TX	Analysis of survey data to identify correlates of student walking to school	Parent-reported student walking to school, Personal attitudes and behaviors, School and peer influence factors, Physical environment factors	Among physical environment factors, negative correlates were distance, safety concerns, presence of highways/freeways, convenience stores, office buildings, and bus stops Among personal and social factors, negative correlates of walking to school included parents' education, car ownership, and school bus availability Positive correlates included parents' and children's positive attitude and regular walking behavior, and supportive peers	Moderate
156	Zimring et al. 2005	Influences of building design and site design on physical activity: Research and intervention opportunities	Review	Studies (n=unspecified)	Review of studies focused on PA and building and site characteristics; development of 'working model' to consider correlates of PA at building and site scales	N/A	Potential for PA impact of building elements such as point-of-choice prompts, site selection, building programming and design Recommendation for further research, especially in public buildings	Preliminary

The following addresses school built environment PA determinants by relative strength of evidence:

Strong to Moderate Evidence

Evidence from 6 studies was deemed strong based upon the defined study design criteria. Of these, 5 focused on school playground interventions, and 1 addressed the student PA impact of school gardens. There was cross-sectional support for the significance of some variables identified in these studies, and also a strong study design of a playground intervention with null results.

Playground Markings and Equipment

A cluster-matched controlled trial at 8 schools in Wales and England found that playgrounds painted with multicolor ground markings – including details such as castles, clock faces, mazes, ladders, letter squares, hopscotch, and animals – increased children’s physical activity levels [82]. An Australian cross-sectional study at 23 primary schools showed that fixed play equipment and painted court and play-line markings were positively associated with MPA, while provision of loose equipment in the playground was associated with more vigorous physical activity (VPA) [77]. A cluster-matched trial at 26 elementary schools in 1 English city, showed that playground improvements had significant positive effects on physical activity levels; specifically, play areas were color-coded red for sports, blue for multiple activities, and yellow for quiet play, and included corresponding equipment [83]. A cluster RCT at 7 Belgian elementary schools demonstrated that provision of game equipment during recess increased children’s MVPA [84]. However, another cluster RCT at 40 Belgian public preschools found that introduction of play equipment and playground markings did not impact MVPA [85].

Playground Availability and Safety

Analysis of direct observation data from a cluster-matched controlled trial at 2 New Orleans elementary schools showed that the number of children outdoors and physically active was higher when the school playground was accessible and had supervision, including after school hours. Based on a school-based survey, there was also a decline in students' sedentary activity with increased playground availability and safety [86]. In a cross-sectional study, focused on adolescent girls, schools with accessible PA facilities outside of school hours were associated with lower BMI but not with time in MVPA [87].

Presence of School Gardens

While a 2007 comprehensive review of research on school gardens found equivocal evidence of school gardens' impact on student PA [88], a recent cluster RCT in 12 socio-economically and geographically diverse New York State elementary schools showed that installation and use of school gardens induced higher levels of student school-time PA [64].

<u>Moderate Evidence</u>

Studies with moderate evidentiary strength denoted other variables related to school grounds.

Presence and Renovation of Schoolyard Playgrounds

The number of permanent playgrounds in schools has been positively associated with MVPA in elementary school students [89]. In a study of twenty urban schoolyards, no particular playground attribute was found to be significantly associated with proportion of active playground users, while the total number of play features and availability of shade were associated with higher utilization [90,91]. Another study evaluating the introduction of renovated schoolyard spaces at Denver schools also found no impact of specific features, although overall utilization increased [92,93].

Outdoor PA Facilities

A study of 130 Norwegian schools showed that students at schools with more outdoor activity facilities reported being significantly more active [94], and another study found that students exhibited the highest levels of PA in an outdoor facility with a handball goal [95]. Positive association between number of active outdoor school facilities and middle school girls' PA has also been demonstrated [96]. Research on adolescents in 3 U.S. metropolitan areas showed that built-in facilities on the school grounds (e.g., basketball hoops, soccer goal posts, running/walking track) were positively associated with PA [97]. A study of 74 Texas public schools showed that students' time in MVPA was greater in PE classes held outdoors vs. indoors, generally supporting ample outdoor facilities in school environments [98]. This result corroborated long-established knowledge that children tend to engage in more PA in outdoor vs. indoor environments [99,100]. A UK study also found that the overall number of sports facilities provided at school was positively associated with PA [101], and a U.S. study found association of after-school field accessibility with PA [57]. A California study at 24 schools showed that permanent facilities such as basketball hoops and courts, other sports courts, baseball backstops, etc., along with supervision, were associated with more MVPA [78]. Students' perceived higher importance of school-based PA facilities and equipment has also been associated with higher PA [102], and provision of PA facilities with recess PA [103].

'Nature' in the Schoolyard

A Canadian study, based on a survey of teachers, parents, and school administrators, suggested that school grounds should provide "adequate space, diverse play opportunities, and interaction with natural elements" [104]. A subsequent study by some of the same researchers found that green areas encouraged a high percentage of children toward MPA, vs. a paved, stepped courtyard being associated with high levels of sedentary, seated activity [105]. Another study indicated that schoolyards with ample trees and shrubbery were associated with more PA [106]. Since green school grounds provide opportunities for a greater range of physical activity than the more common asphalt or turf areas, they could play a role in promoting physical activity in children with wide ranging preferences [105]. Supporting this notion was a study comparing PA in 2 independent samples of young children during unstructured recess before and after a schoolyard intervention including a looping cycle path, increased open space in the playground, and a new grass hill. It found fewer sedentary intervals, more intervals in light PA, and higher odds of MVPA in the intervention scenario [107]. The authors recommended environmental changes supporting "novel movement experiences in more expansive spaces" [107].

Schoolyard Surface Materials

Findings regarding surfacing materials were mixed. One study found that both boys' and girls' activity levels were higher in soft-surfaced vs. other areas of schoolyards [94], while another study found that MPA was higher on hard-surfaced courts [77]. A study focused on Australian 6th graders showed that grassed surfaces were positively associated with MVPA during recess, but not if shaded [108].

Other studies with moderate evidentiary strength identified PA relationships to school size and PA facilities, and school proximity to other facilities.

School/Campus Size

Larger per student campus and school building areas have been positively associated with PA among students at 10 middle schools [109].

School Indoor PA Facilities

Research on children from disadvantaged backgrounds showed that those attending a school with a gymnasium had more PE time per week than those attending schools without such a facility [110], and a study at 30 Canadian elementary schools showed that students with interschool physical activity programming due to the schools' lack of adequate facilities engaged in less MVPA [111]. Earlier studies also supported associations between availability of indoor PA facilities at schools and PA outcomes [112]. Some schools have included a gymatorium, in addition to a gymnasium, and instead of a traditional auditorium; a gymatorium has a stage and seating that is flexible or on one side, and provides space for PA when an auditorium is not needed [113]. A combination of recreational equipment and staff training has produced increases in MVPA in elementary school students [79], indicating that activity spaces allowing for active adult supervision may be important.

School Proximity to Other PA Facilities

In a study of adolescent girls, school proximity to recreation facilities was associated with PA [114]. Another study, focused on 12th graders, found that those who attended schools with five or more physical activity facilities within a 0.75 mile buffer zone around the school were more physically active than those attending schools with fewer than 5 nearby physical activity facilities [115].

Many have recommended focus to ensure active commuting to school is safe and convenient [116], and 20 cross-sectional studies addressed active commuting as a means to improve child and adolescent PA. Several inter-related school area environmental constructs emerged from these studies.

Safety

Safety concerns of parents and/or students were major barriers to active commuting [117-122], and Safe Route to School Program sites (created via funding for urban form and safety improvements, such as installation or widening of bicycle lanes, sidewalks, and crosswalks at and near schools) have been associated with higher walking and cycling commuting compared to unimproved sites [123]. In the safety realm, lack of crossing lights [124] and high traffic on the route to school [120,124] also have served as barriers to active commuting. A qualitative study at schools in 7 U.S. states produced similar findings, identifying sidewalks, crosswalks and crossing guards, and sense of personal safety as influential factors in active commuting [125].

Population Density

Some studies noted differences in active commuting behaviors between urban, suburban and rural children, with those in areas of higher population density generally walking more [75,126-128], and those in rural locations more frequently driven to school by parents [129]. Among girls, higher proportion of accessible open land and lower mix of land uses around school were associated with higher fat mass index [130]. Policy recommendations have included moving away from sprawling to more traditional neighborhood plans [131].

Neighborhood Walkability

Several studies showed that neighborhood walkability, a construct encompassing safety, land use, service access, density, and aesthetics, was significantly associated with students' active commuting [121,132-134]. Research has revealed economic and ethnic disparities in neighborhood walkability [135]. But, while high walkability was associated with more active commuting to school in high-income neighborhoods, it was not related to active commuting in low-income neighborhoods [136]. Those with more active destinations in the neighborhood and more places they enjoyed walking were more likely to commute actively [118].

Distance to School

Studies have shown that distance to school was a barrier to active commuting [117,122], and that those who lived closer to school were more likely to commute actively [118,127,134], in particular if they lived <800 meters from school [124]. In addition, those living closer to school spent more time in MVPA [137]. A Belgian study determined criterion active school commuting distances to be 1.5 kilometers for walking and 3.0 kilometers for bicycling [138].

Connectivity of Route from Home to School

Lack of a direct route to school has been identified as a barrier to active commuting [117]. High route connectivity with low traffic volume was positively associated with walking to school, while regular walking was less likely in areas with high connectivity and high traffic [132]. Retrofitting neighborhoods with walking trails or paths had an impact on neighborhood residents' PA overall, but was not shown to increase students' active commuting to school in one study [139].

<u>Moderate to Preliminary Evidence</u>

Several studies with moderate and preliminary evidence addressed elements of the school interior and classroom environments.

Open Interior Space and 'Outside' Elements

Traditional classrooms with rows of desks and little room or opportunity to move have been the norm for some time in the U.S., but some evidence supports redefining classroom design to support PA and other positive student outcomes. A study of 40 students using within-subject PA measures in a Minnesota city tested the impact of an activity-oriented, open, spacious school environment mimicking the appearance of and called "The Neighborhood." In this design, representations of environmental elements, such as building facades and a street, were brought to the school interior. The study concluded that children exposed sequentially to 3 distinct school interior environments were more physically active in "The Neighborhood" compared to a traditional school with rows of chairs and desks in the classroom, and compared to a traditional school with stand-biased desks in the classroom [140]. The study also demonstrated cross-sectionally that students in "The Neighborhood" school were just as physically active as other similar students on summer vacation [140].

Flexible 'Moving' Classroom

Another study compared students' PA in 'moving school' classrooms at a German school vs. in traditional classrooms at a Belgian school with socio-demographically similar students. The 'moving' classrooms were defined by moveable and modular furniture, ample space for frequent and varied in-classroom navigation and movement supported by an activity-promoting school social environment. Findings were that children in the 'moving' classrooms were more physically active, and had better posture and lower prevalence of back pain [141].

Stand-biased Desks

A small clustered RCT in 4 classrooms at 1 Texas school found that exposure to stand-biased desks with stools significantly increased class-level energy expenditure [142], and a related study using within-subject measures and no control group found that students' energy expenditure increased with use of stand-biased desks [143]. A qualitative article about this stand-biased desk intervention reported that students' focus and attention also improved, and that students generally preferred to stand vs. sit [144]. With adjustments, these desks also supported variations in children's anthropometry and postures [144], important ergonomic considerations [34,145,146].

Dynamic Furniture

Scientists have argued that the design of a humane working space should consider that bodies, especially growing bodies, are not meant to sit still for long periods of time, and that furniture can support or hinder natural moving behaviors [2,147]. 'Dynamic furniture' is designed to foster children's natural physical movements, and includes pieces such as ergonomic roll-swivel chairs with seat surfaces that move in three dimensions, adjusting to subconscious body position changes and encouraging the body to change positions. Such seating has been shown to have a rhythmic and postural effect, activating the proprioceptive system and improving circulation, raising body temperature [2,148], and improving learning outcomes [2]. A small lab-based study found that children had significantly higher average accelerometer-measured activity counts while using dynamic seating vs. traditional school furniture, although impact on energy expenditure was not detected [65].

Several studies with moderate or preliminary evidentiary strength addressed stair use, mostly among adults. Although stairs tend to be the primary routes of vertical circulation in school environments, some school facilities offer navigation choices between stairs and other routes. Especially among younger student populations, school navigation routes are led by adult teachers, making adult choices potentially relevant.

Stair Spatial Variables

Several spatial variables have been associated with stair use in adults: travel distance from stair to nearest entrance and elevator, occupant load of stair, accessibility of stair, area of visual field from stair, number of turns required for travel from stair to closest entrance, the most integrated path [149], as well as general stair visibility [150].

Stair Prompts

In a study of a clinic, an academic building, and a multi-story housing structure, stair use increased in all settings after posting of stair prompts; at the housing site, stair use remained significantly higher than baseline nine months after the prompts were initially posted [151]. In another study, a motivational component in elevators had no effect on stair use, while the addition of a point-of-choice prompt had a significant effect, indicating that visibility of a prompt at the time of choice encouraged behavior change [152]. In other studies, stair motivational signage was associated with increased stair use [150,153]. A systematic review recommended stair prompts as an evidence-based strategy for increasing stair use [154]. Another review concluded that point-of-choice prompts encouraging stair use can work, although the most effective messages and long-term impact have yet to be determined [155], and others have noted that stronger evidence is desirable [156].

Stair Aesthetics

Use of aesthetic features such as artwork and music were shown to increase use of existing stairs vs. elevators in a limited study in 1 university building [157]. In addition to stair prompts, stair visibility and natural light in stairs have been positively associated with stair use [150].

Preliminary Evidence

Work in public health and in human factors engineering has begun to explore use of technologies beyond what is typically available in schools.

Mobile Technologies

Some emerging work has focused on leveraging social marketing in youth PA programs [158], pointing to potential roles for school spaces and mobile and real-time tracking technologies in schools, such as school-based dashboards [159] that could be used to track PA program results in real-time.

Virtual Reality Environments

Recent work has leveraged a virtual reality environment in a school-based PA program. This non-controlled, longitudinal study, called the “American Horsepower Challenge,” produced preliminary evidence that design and integration of a virtual reality environment within the school environment could play a role in increasing youth PA. The program used technology to feed real-world step data from 1,465 middle school students into a virtual designed environment where they could participate in an athletic competition. The virtual environment was intended to motivate all students, even those without particular sports skills, to contribute to winning the competition for their school simply by walking and moving, and participants’ pedometer-measured PA increased significantly over the course of the school program [160].

Practice-Based Inputs

New York City’s *Active Design Guidelines* were oriented to the perspective of design and spatial decision-making. Some relevant recommended practices applicable to schools and promotion of PA included arranging the building's program in consideration of the age of users; massing building components in consideration of the scale and age of users and to enhance views of outdoor spaces; providing visually appealing environments along navigation pathways; and allowing for ample daylighting and views to the outdoors from navigation and other areas [45].

Current best practice recommends designing school classrooms to be large enough to accommodate ample movement, to be flexible and mobile in layout to promote activity and accommodate multiple learning and teaching styles, and to make fitness facilities visible (for social modeling) and attractive to reinforce the idea that physical activity is desirable and fun [161]. Architecture and design professionals tend to share and learn best practice via case studies and competitions, and sometimes these are published in architectural and educational journals. This work generally supports school designs that include natural lighting, ample room for movement and flow, and shared community spaces [162]. A subset of the architectural literature on school design is sponsored by industry organizations focused on promoting specific product use in school construction [163,164], highlighting a need for objective and reliable resources for designers.

Physical Activity Design Guidelines for School Architecture

Children's school-related PA has been conceptualized previously in categories of commuting PA, recess PA, class PA, and overall PA [165], pointing to potential programmatic intervention areas but not necessarily to built intervention opportunities. To create a tool oriented to the school design process and evaluation of impact on PA outcomes, delineation of domains from a design practice perspective was necessary. Findings from literature suggested that decisions throughout the design process, from school siting, to types and placements of school buildings and PA facilities, to furniture specifications, can be relevant to a health-promoting school. Thus, design strategies were organized into spatially- and process-oriented ‘designable’ domains.

This new practical tool, *Physical Activity Design Guidelines for School Architecture,* synthesizes evidence and best practice into strategic actions designers can take in the interest of increasing child and youth PA in and around school settings. The *Guidelines* are intended to be a reference for school designers, educators, and researchers that will evolve with further growth and sophistication of the evidence base. Along with the strategies in each domain, relevant published empirical and review studies are denoted, for those wishing to delve into the nuances of particular studies' findings, and relative alignments and disagreements. Drawing upon New York City's definitions and symbols for its *Active Design Guidelines* [45], the substantiality of research-supported evidence for each design strategy is rated as follows:

- ★ Substantial Evidence – 2 longitudinal studies or 5 cross-sectional studies supporting a relationship between the school built environment strategy and PA.
- ☆ Emerging Evidence – empirical research supporting the strategy exists, but is of a preliminary or pilot nature.
- ◊ Best Practice – theoretical support and/or practice-based experiential support for the strategy, but no formal evidence base.

The *Design Guidelines* appear in Table 1.2. The 1st domain addresses school siting and connections to community. Its strategies are primarily intended to support students' active commuting to and from school. The 2nd domain, building massing and programming, has not been addressed in the literature related to PA, but it is an essential and substantial process in designing school environments. Therefore, these strategies largely draw upon best practice, and they are intended to lead designers to consider how massing and programming decisions could impact PA. The 3rd domain addresses school indoor and outdoor fitness facilities, with evidentiary support for specific strategies ranging from substantial empirical evidence to best practice. Empirical studies have pointed to a need for adequate school spaces to integrate physical activity throughout the school day.

Although there are few empirical studies of PA directly addressing the 4th domain, classroom design, the strategies presented draw upon this work, as well as encourage spatial designs to accommodate ample movement and activity breaks. Strategies for the 5th domain, outdoor learning areas, draw upon emerging work revealing the benefits of gardens and other outdoor spaces as active learning environments. The 6th domain, active play and leisure areas, draws upon emerging evidence in playground design, and upon theory and best practice. Active navigation areas, the 7th domain, draws upon emerging empirical work along with best practice. The 8th domain, signage and wayfinding, recommends using point-of-decision prompts for stairs and other school-based PA opportunities. In addition, strategies suggest that wayfinding systems developed by designers should encompass PA goals. Specifications for detached furniture are often developed by individuals and/or groups distinct from those who develop the site and building plans, and therefore these strategies are grouped into a 9th domain. Current evidence indicates that dynamic and stand-biased school furnishings could have a positive impact on students' PA.

Finally, the 10th domain, technology and virtual reality environments, builds on emerging work in both public health and human factors engineering. These strategies are intended to prompt school designers to consider potential health impacts of new technologies in the school facility infrastructure, as well as to consider designing virtual reality environments as extensions of the school educational environment.

Table 1.2. Physical Activity Design Guidelines for School Architecture.

Design Domains	Strategies	Relevant Literature	Evidence Rating	Illustrations
1 SCHOOL SITING AND COMMUNITY CONNECTIVITY				
	➢ Consider locating new schools and/or renovating schools in higher density neighborhoods where students live close to school when possible	[75,117,120, 126-128,130, 134,137]	★	
	➢ Consider safe walking/cycling and public transportation access in choosing school sites	[75,117,118, 120-126,132, 133,136,138, 139]	★	
	➢ Structure built and natural elements on and around the school site for variety and visibility that will be pedestrian-friendly and pedestrian-safe	[105,132]	☆	
	➢ Consider potential cultural, gender, and neighborhood differences in perceptions of safety and aesthetics in potential active commuting routes around schools	[119,120,127,129,135]	☆	
	➢ Connect to existing and/or planned community trail networks, and locate schools near other community and recreational facilities where possible	[114,115,139]	☆	

Design Domains	Strategies	Relevant Literature	Evidence Rating	Illustrations
2 BUILDING MASSING AND PROGRAMMING				
	➢ Consider age-appropriate scale in massing of building components		◊	
	➢ Consider building connections and spatial patterning as opportunities to promote physical activity		◊	
	➢ Orient building to amplify outdoor views		◊	Fig. 1.3
	➢ Mass and orient building to allow penetration of natural light from most areas of the building interior		◊	
	➢ Locate building functions to encourage bouts of walking throughout the school day		◊	Fig. 1.4
	➢ Provide convenient and secure covered bicycle storage on school sites		◊	
	➢ Provide community-use spaces that can accommodate healthy community activities (e.g., local farmer's market, active participatory events)		◊	Figs. 1.5, 1.6
	➢ Allow for ample school and grounds space per student	[109,128]	✰	

Design Domains	Strategies	Relevant Literature	Evidence Rating	Illustrations
3 SMART FITNESS FACILITIES				
	➢ Provide multiple and varied outdoor fitness facilities	[78,87,94,97,101,102,112]	★	
	➢ Include an indoor gymnasium, ideally with an indoor track and ample space to support vigorous PA and PE curricula, especially in locations with frequent inclement weather	[78,87,94,97,101,102,112]	★	
	➢ Provide a 'gymatorium,' in addition to a gymnasium, and instead of a traditional auditorium; a gymatorium has a stage and seating that is flexible or on one side, and provides space for PA when an auditorium is not needed		◊	
	➢ Create visibility of fitness and physical activity activities from other parts of the school, such as navigation areas		◊	Fig. 1.7
	➢ Locate fitness facilities such as gyms and pools centrally if possible for access and visibility		◊	
	➢ Incorporate dedicated interior spaces for a range of types of fitness activities (e.g., smaller, quieter rooms for yoga, Tai chi, etc. in addition to a large gymnasium)		◊	
	➢ Include both soft-surfaced (e.g., soccer/footballs field), and hard-surfaced (e.g., basketball and tennis courts) exterior sports areas	[96,101,112]	☆	
	➢ As sites allow, include hiking and biking trails, and natural areas	[104,107,139]	☆	
	➢ Design indoor and outdoor PA facilities to accommodate use of both fixed and movable equipment	[77,83,89,104,105,107,176]	★	
	➢ Design floor markings that can be used for numerous activities, in addition to using standard court markings in gymnasiums and on hard-surfaced outdoor courts; consider age-appropriateness for types of markings	[77,82]	☆	Fig. 1.8
	➢ Incorporate natural lighting and outside views from interior facilities and provide visibility to outdoor facilities		◊	

Design Domains	Strategies	Relevant Literature	Evidence Rating	Illustrations
4 ACTIVE CLASSROOMS				
	➢ Provide ample room for children and teachers to move in and around the classroom, supporting potential activity breaks, as well as PA programs	[140,141]	☆	Fig. 1.9
	➢ Design modular areas and learning hubs, including activity and reading nooks		◊	
	➢ Provide a flexible classroom layout to allow for multiple and changing configurations	[140,141]	☆	Fig. 1.10
	➢ Allow space for student-defined learning areas		◊	
	➢ Provide easy access from classrooms to outdoor play and learning areas, especially for young children		◊	
	➢ Provide active time-out space and equipment		◊	
5 OUTDOOR LEARNING AREAS				
	➢ Provide outdoor classroom spaces, with cover and/or shade as appropriate for the local climate	[94,98]	☆	
	➢ Locate outdoor classrooms adjacent to outdoor and natural learning opportunities		◊	Fig. 1.11
	➢ Include gardens as learning and activity areas, in addition to trails and natural areas	[64,88,105,107]	☆	
	➢ Provide drinking fountains with good-tasting water in outdoor learning areas		◊	
	➢ Provide infrastructure (power, water, lighting) to support high utilization of outdoor classrooms and learning areas		◊	

Design Domains	Strategies	Relevant Literature	Evidence Rating	Illustrations

6 ACTIVE PLAY AND LEISURE AREAS

Design Domains	Strategies	Relevant Literature	Evidence Rating	Illustrations
	➢ Include both hard and soft surfaces, green or 'natural' areas, and variations in sun and shade, to promote varieties of activity and exploration of nature in outdoor playground areas	[77,104-107]	★	
	➢ Renovate and/or build playgrounds and break areas to include fixed play equipment with age-appropriate challenge, and less structured space for use of portable equipment	[77,84,89-93,95,103,104]	★	Figs. 1.12, 1.13
	➢ Include multi-color ground markings in playground areas to delineate spaces for many types of activities	[82,83,85]	✰	
	➢ Ensure sufficiently large interior play and gathering areas in regions with frequent inclement weather		◊	
	➢ Provide drinking fountains with good-tasting water in play areas		◊	
	➢ Define arrangements to encourage active adult/supervisor interactions with children in play, recess, and break areas	[83,86,108,176]	✰	

7 ACTIVE NAVIGATION AREAS

Design Domains	Strategies	Relevant Literature	Evidence Rating	Illustrations
	➢ Locate visually appealing stairs in prominent circulation areas with natural lighting, and place elevators less conspicuously	[149,150,157]	✰	Fig. 1.5
	➢ Provide alternate routes from place to place where possible		◊	
	➢ Provide variation and interest in views (indoor/outdoor) throughout navigation areas and pathways		◊	
	➢ Install features of interest that serve as 'movement temptations' in navigation areas to encourage physical interaction with built elements; possibly include elements typically found outdoors	[140]	✰	Figs. 1.14, 1.15

Design Domains	Strategies	Relevant Literature	Evidence Rating	Illustrations
8 SIGNAGE AND WAYFINDING				
	➢ Include signage with point of decision prompts for stair use and other PA opportunities	[150-156]	★	
	➢ Develop a wayfinding system that addresses appropriate active navigation (e.g., walking, running) throughout the school and grounds		◊	
	➢ Incorporate educational signage that encourages physical activity, promotes its benefits, and is also age-appropriate and fun		◊	Fig. 1.16
	➢ Use educational signage to prompt specific physical activity opportunities, beyond stair use		◊	
	➢ Integrate educational signage and wayfinding graphics into the learning curriculum, with potential for social marketing use		◊	Fig. 1.17
9 FURNITURE SPECIFICATIONS				
	➢ Specify dynamic furniture that is ergonomically appropriate for age, and embraces children's natural tendency to move and fidget	[2,65,141,148]	✫	Fig. 1.18
	➢ Specify adjustable, stand-biased desks with stools, and modular furniture, in classrooms	[142-144]	✫	
	➢ Specify a variety of furniture to promote choice options and changes in postures for group work, free work, individual work, etc.		◊	Fig. 1.8
	➢ Specify furniture with casters to promote agile configurations and novel settings		◊	

Design Domains	Strategies	Relevant Literature	Evidence Rating	Illustrations
10 MOBILE TECHNOLOGIES AND VIRTUAL DESIGNED ENVIRONMENTS				
	➢ Incorporate infrastructure for use of technology to promote mobile learning and exploration, and opportunities for health-oriented social marketing fostering PA motivation and competition (e.g., support for school-based mobile devices, real-time feedback dashboards, etc.)		◊	
	➢ Consider designing virtual reality spaces in conjunction with school physical spaces to support PA across the student athletic ability spectrum	[160]	✩	

Evidence Rating Key:
★ Substantial Evidence = 2 longitudinal studies or 5 cross-sectional studies supporting a relationship between the school built environment strategy and PA
✩ Emerging Evidence = empirical research supporting the strategy exists, but is of a preliminary or pilot nature
◊ Best Practice = theoretical support and/or practice-based experiential support for the strategy, but no formal evidence base
(Rating system adopted from the City of New York's *Active Design Guidelines* [45].)

Examples and Illustrations

Many of the *Design Guidelines* have been put into practice at the Carter G. Woodson Education Complex, a primary and elementary school in Buckingham County, Virginia, and at the Fridtjof Nansen School in Hannover, Germany. Visual illustrations of implementations of several design strategies are referenced in Table 1.2, and are shown in Figures 1.3 to 1.18.

Figure 1.3. Library of the Buckingham County Primary and Elementary Schools at the Carter G. Woodson Education Complex, Dillwyn, Virginia. Much of the facility's interior includes ample glazing for natural lighting and views of nature. (Photo Credit: Alan Karchmer/VMDO Architects)

1.4. First Floor and Site Master Plan of the Carter G. Woodson Education Complex, Buckingham County, Virginia. The design promotes bouts of walking during the school day, and includes many varieties of age-appropriate physical activity opportunities. (Image Credit: VMDO Architects/Water Street Studios)

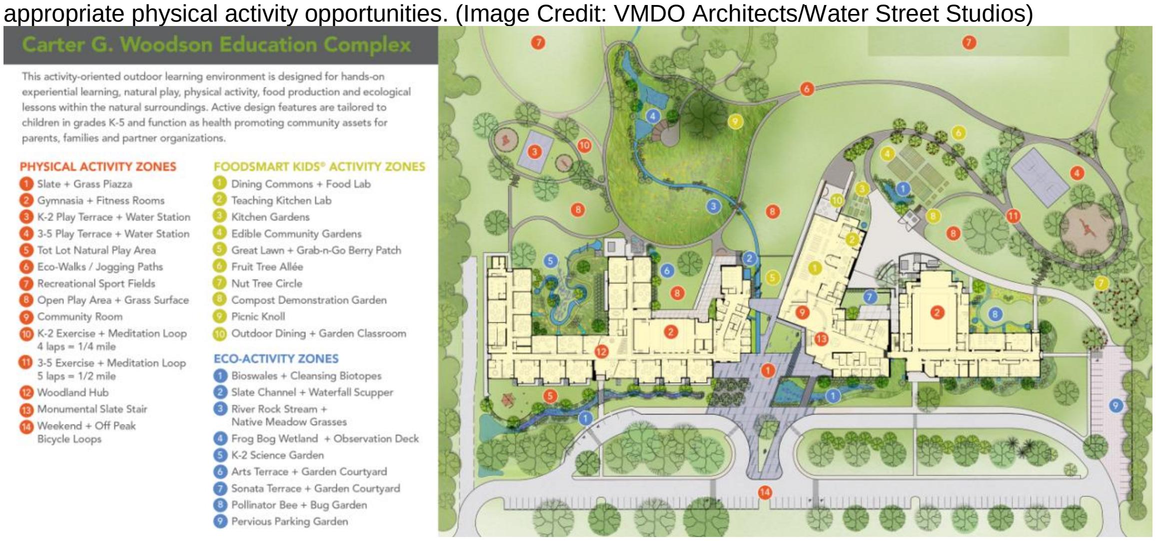


Figure 1.5. The Visually Prominent Main Stairway in the Carter G. Woodson Education Complex, Dillwyn, Virginia is located near the central entry and interior community commons and gathering area. An elevator is available, but located less conspicuously. (Photo Credit: Tom Daly/VMDO Architects)

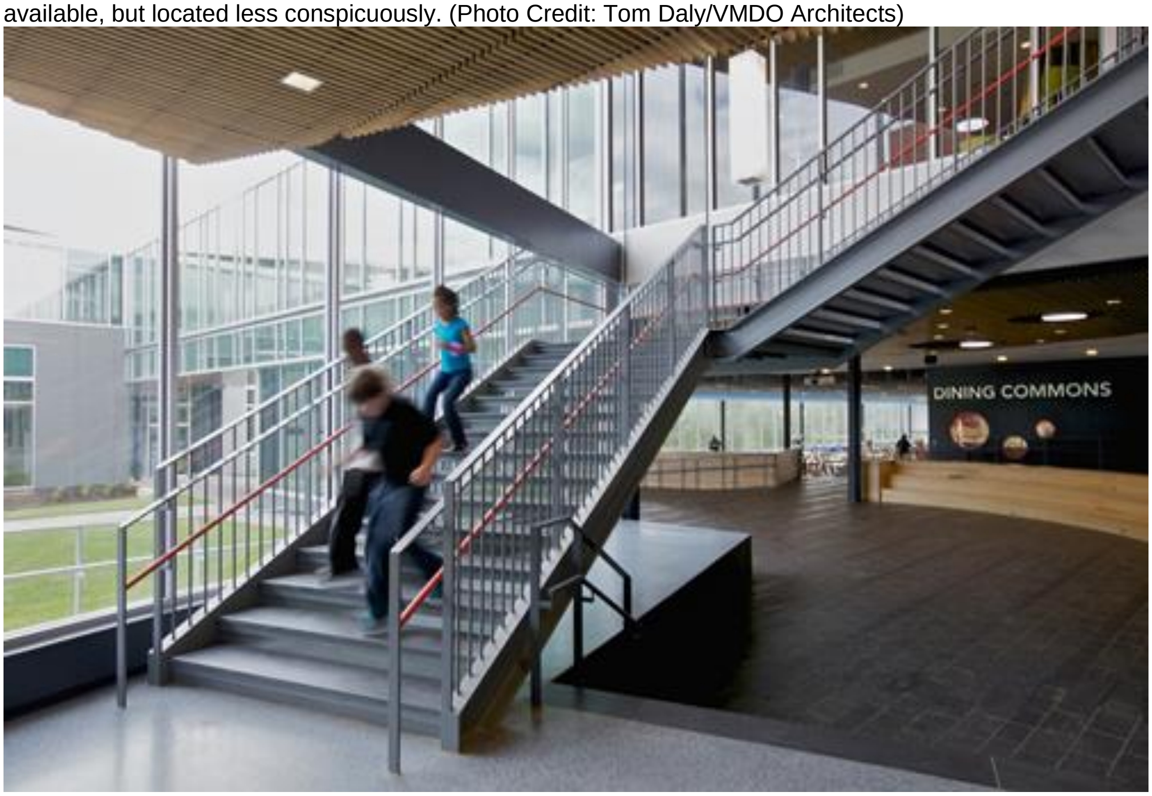


Figure 1.6. The "Tree Canopy" Corridor Intervention in the Buckingham County Primary School at the Carter G. Woodson Education Complex, Dillwyn, Virginia. The structure is intended to entice interactive and active teaching moments and educates about types of trees native to Virginia. (Photo Credits: Tom Daly (left)/Andrea Hubbell (right)/VMDO Architects)

Figure 1.7. “Hangelstrecke” Play Structure at the Fridtjof Nansen School, Hannover, Germany. The corridor installation encourages bouts of physical activity. (Photo Credit: Dieter Breithecker/Institute for Posture and Mobilisation Support)

Figure 1.8. A Classroom in the Fridtjof Nansen School, Hannover, Germany. Mobile, dynamic furniture allows flexibility to combine active movement with learning. (Photo Credit: Dieter Breithecker/Institute for Posture and Mobilisation Support)

Figure 1.9. A Kindergarten Classroom in the Buckingham County Primary School at the Carter G. Woodson Education Complex, Buckingham County, Virginia. Dynamic seating and trapezoid-shaped tables adapt to multiple configurations. The classroom also connects directly to an outdoor play area with rain garden features. (Photo Credit: Alan Karchmer/VMDO Architects)

Figure 1.10. Views from the Hallway into the Gym in the Buckingham County Primary School at the Carter G. Woodson Education Complex, Buckingham County, Virginia draw upon concepts of observational learning and modeling from social cognitive theory, encouraging students to be active. (Photo Credit: Tom Daly/VMDO Architects)

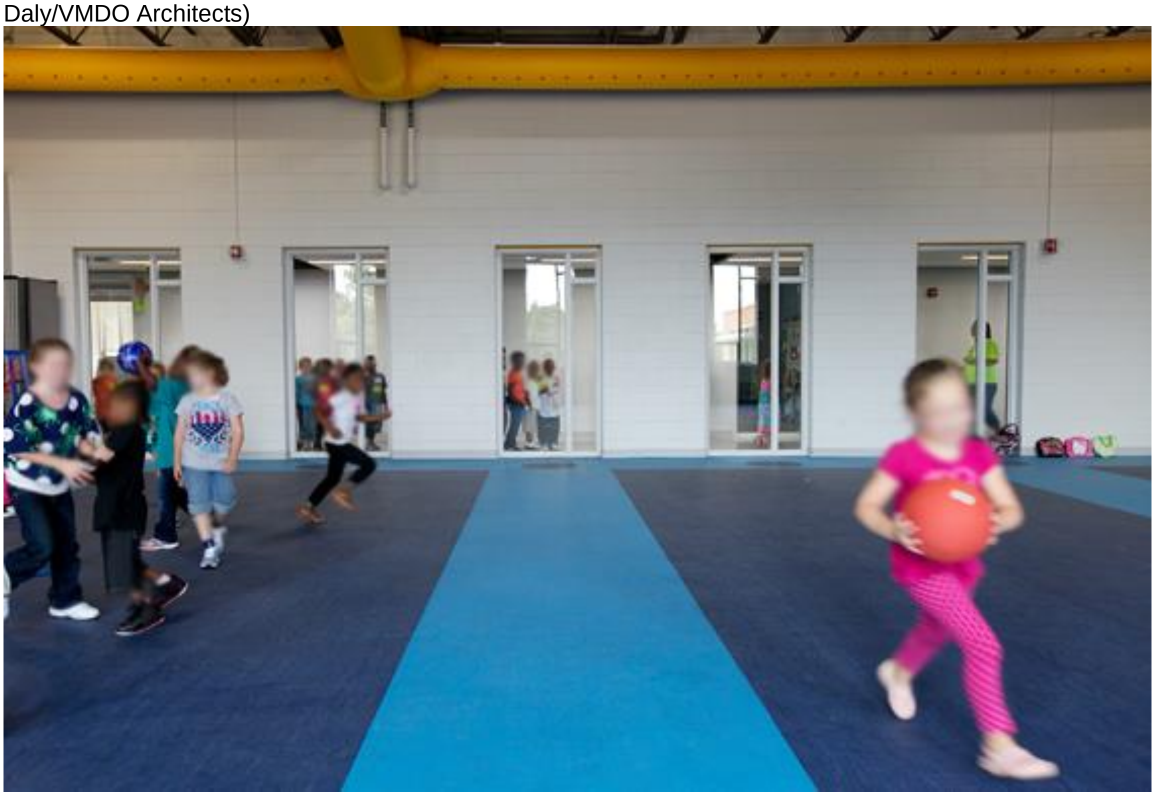


Figure 1.11. The Gym of the Buckingham County Primary School at the Carter G. Woodson Education Complex, Buckingham County, Virginia, includes colored floor markings with wide bands and circles delineating spaces for various types of simultaneous activities. (Photo Credit: Tom Daly/VMDO Architects)

Figure 1.12. The Playground at the Fridtjof Nansen School in Hannover, Germany includes fixed equipment, some of which was built from reclaimed materials, space for moveable equipment and games, and shaded and sunny areas. Water is readily available. Here, the students run up an incline and jump off, enjoying the feeling of weightlessness. (Photo Credit: Dieter Breithecker/Institute for Posture and Mobilisation Support)

Figure 1.13. The Fixed Equipment in the Playground at the Fridtjof Nansen School in Hannover, Germany is designed for age-appropriate challenge. Here, children organize by way of managing hindrances. (Photo Credit: Dieter Breithecker/Institute for Posture and Mobilisation Support)

Figure 1.14. An Outdoor Classroom/Lab at the Carter G. Woodson Education Complex, Buckingham County, Virginia is adjacent to the vegetable and herb garden, edible orchard, interior dining commons, and kitchen lab. A nature trail that runs throughout the school grounds connects to the garden area. (Rendering: VMDO Architects)

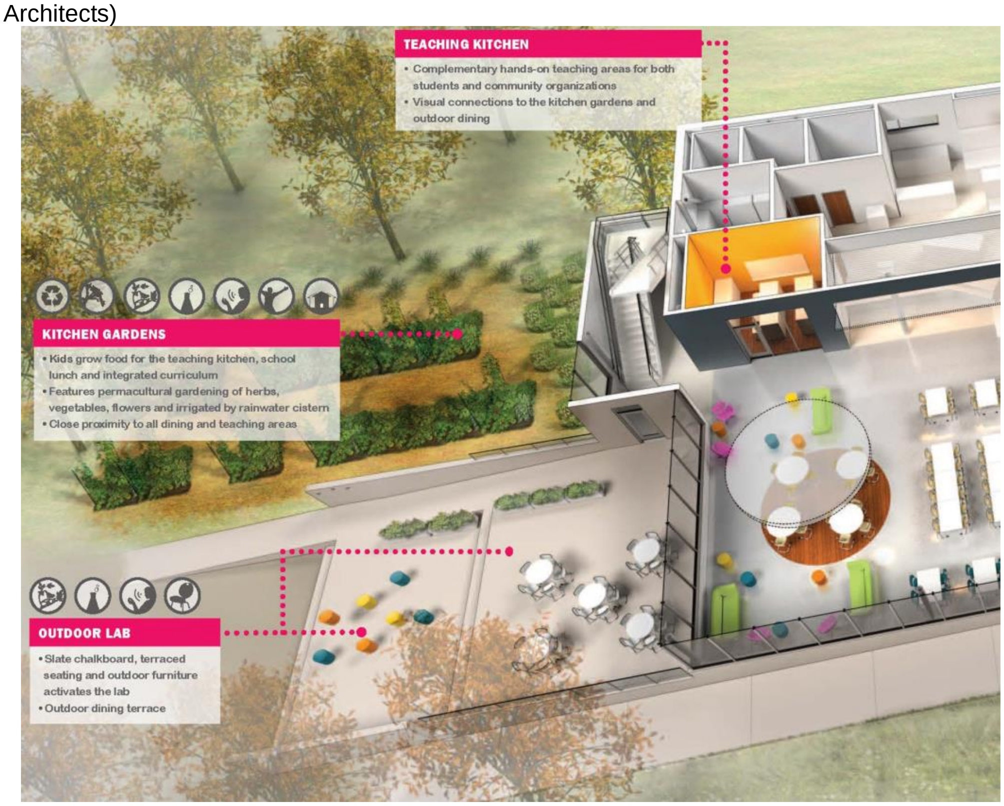


Figure 1.15. Community Spaces in the Carter G. Woodson Education Complex, Dillwyn, Virginia include a food lab, located in close proximity to the community commons with amphitheater seating, the dining commons, corner bakery, monumental stair, and entry, all with ample light and outdoor views. (Photo Credit: Alan Karchmer/VMDO Architects)

Figure 1.16. Open Small Group Learning Labs in the Carter G. Woodson Educational Complex in Buckingham County, Virginia include dynamic furniture such as these stools with curved bases. (Photo Credit: Tom Daly/VMDO Architects)

Figure 1.17. Signage throughout Carter G. Woodson Educational Complex, Dillwyn, Virginia educates children about the benefits of being physically active. (Image Credit: VMDO Architects)

Figure 1.18. The Eco-Based Wayfinding System at the Carter G. Woodson Educational Complex, Buckingham County, Virginia associates a specific color with each grade level, and engages children to interact visually and physically with educational content. (Image Credit: VMDO Architects)

DISCUSSION AND CONCLUSION

The complex causal pathways between environmental factors and human behaviors such as PA are not yet well understood [166,167], but, given need to improve PA behaviors across numerous populations of children, the body of literature associating school environment factors to child and youth PA outcomes is substantial in size and growing. The overall strength of this evidence base remains limited, and longitudinal research of clearly defined variables supporting causal interpretations is warranted. Further explication of built environmental variables and measures, and their causal, mediating, or modifying roles in relation to PA, PA programming, and social environmental variables is needed [96], and ecological models should incorporate context-specific PA and explanatory variable measures [168], as well as strive toward measurement consistency.

One Danish cluster RCT of a multi-component school-based PA intervention – including improvements such as upgrades of outdoor PA areas, construction of leisure areas for adolescents, and improvements in active commuting safety – has reported positive school-time PA effects, but no evidence of impact on students' overall PA [169,170]. These authors noted that the intervention might have been more successful with more focus on social influences. The study findings raise questions as to the degrees, types, and combinations of built and social environmental factors that could have an appreciable impact. There was little qualitative work in the set of literature reviewed, and rigorous studies including inductive qualitative methods may be useful to inform such understanding of relevant environmental variable definitions and inter-relationships.

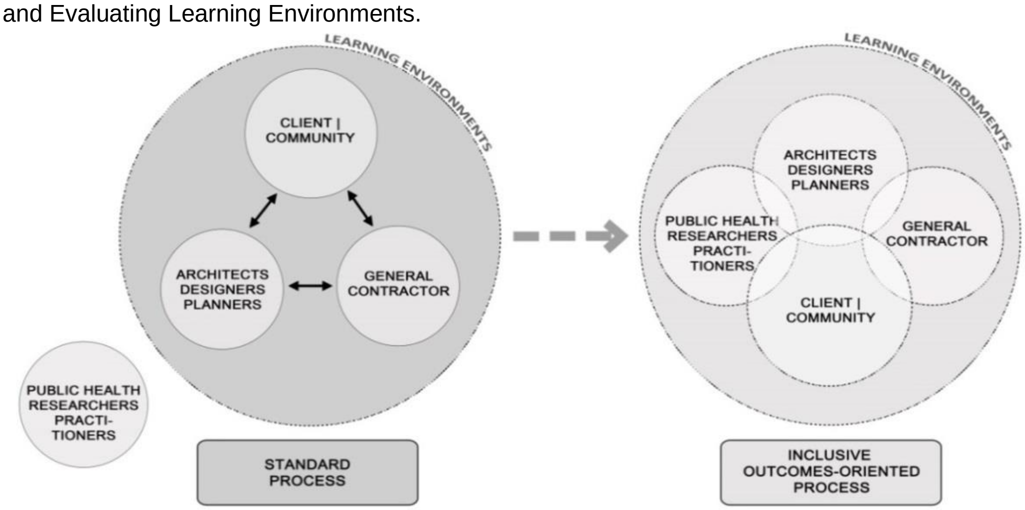
In support of building and evolving school environments to promote PA now, and of growing our knowledge as to the relationships between school environments and PA, the *Physical Activity Design Guidelines for School Architecture* mitigate a sizeable methodological and knowledge gap between PA-focused research and school design practice. As the evidence base around PA and school environments continues to grow, the *Design Guidelines* will necessarily evolve. As they stand, however, the *Design Guidelines* contribute substantively to the literature, both as a synthesis of current knowledge and as a practical resource for school designers, decision-makers, and scientists.

The *Design Guidelines* have several limitations. They draw from a fairly young and undeveloped evidence base, as well as from theory and best practice. Strategies are intended to focus school built environment design decisions on student PA outcomes, but they do not comprise a "formula," nor do they identify specific design solutions, which eventually must conform to building codes and include numerous details from spatial forms and ordering to material specifications. Potential tensions between strategies, for example, locating schools in denser areas while also providing ample facility space, must necessarily be resolved based upon the context and relative goals of a project. The K-12 population encompasses a wide age range, and all strategies may not necessarily generalize to all ages, geographies, and socio-demographic groups. The strategies focus on elements of the school physical environment and infrastructure that can be designed, but this focus should not preclude explorations of relationships to social environment and infrastructure. It is also not yet clear whether PA behaviors associated with school environment changes may carry over to non-school time, or to other settings later in life. Finally, the literature searches were completed by June 2014, and further work has emerged since this time. However, the investigator has not observed any subsequent studies that would substantially change the content of the *Design Guidelines*.

In the realm of design practice and school building, the *Design Guidelines* provide a succinct translation of current evidence to actionable strategies school designers and decision-makers can access and use to orient their work toward desirable PA outcomes. The *Design Guidelines* can thus function as a component of designers' 'toolkit': The language of the strategies is intended to be specific enough to encourage solutions supporting PA, and at the same time general enough to allow for diverse creative solutions that draw upon local culture and context that may be unique to any given project. The *Design Guidelines* also provide designers with opportunities to leverage synergies with sustainable practices and universal design. For example, school ground trails, along with a wayfinding and signage system, might incorporate elements of a local ecosystem, and educational point of choice prompts for PA; school garden design could consider how every student, across the spectrum of mobility and ability, would be able to participate in garden activities; and playground design can include multiple structured and unstructured facilities to accommodate and challenge a range of PA abilities. The *Design Guidelines* are also flexible enough to help inform school administration and designer decisions, in consideration of evidentiary support, from small-scale renovation to an entirely new site and facility. For example, while school siting may not be relevant to renovation at an existing site, other strategies at a range of scales, from renovating play areas to specifying mobile and dynamic classroom furniture, could well be applied as funding allows. As with any built feature, the costs of construction, maintenance and needed staff support should be considered in light of needs and potential positive health outcomes. Anecdotally, based upon the Virginia school project illustrated above, focus on health outcomes at the genesis of the school design process resulted in a health-oriented facility that cost no more than it would have otherwise.

In the realm of science, the *Design Guidelines* serve as a structured source for generating testable hypotheses related to school environments and child and youth PA outcomes. Hypotheses could be developed from the *Design Guidelines* alone, and could also take into account other potential influences. For example, the notion that a built environment change could modify or mediate the effects of a PA program or social intervention could be explored. Such hypotheses can inform future research collaborations, designs and projects that will strengthen the evidence base. It is important to consider research and evaluation opportunities before designing or redesigning a school [156]. The transdisciplinary process employed was successful in focusing a particular school design project on student's PA and health outcomes, in conjunction with learning outcomes. We recommend that others consider this transdisciplinary, inclusive model, as illustrated in Figure 1.19. Public health expertise should be integrated into the learning environments design process from the outset, so that health oriented goals are of primary focus, and so that success in achieving such goals can be rigorously evaluated.

Figure 1.19. Models of Standard Process and Proposed Transdisciplinary Inclusive Process for Designing and Evaluating Learning Environments.



Assessment tools have been developed to reveal issues in community and school environments' support of PA [171,172], and community-level work has indicated that concerted partnerships focused on designing environments for active living have produced positive results [173-180]. Efforts have emerged to promote health via legislative and funding policies [58,181-188], and researchers have recommended creation of policy on school-community partnerships specifically to promote PA in schools [189]. Others have noted that effective transdisciplinary collaborations are needed [10], including government, corporate, community, and non-profit stakeholders to create health-promoting environments in diverse communities [190]. The *Design Guidelines* may facilitate focus of industry and education standards on building schools with the goal of improving health outcomes. It is in the interest of the design, school planning, and public health professions, as well as in the interest of communities, to engage in and inform such leadership and policy decisions.

CHAPTER 2

Impact of Active School Design on School-Time Sedentary Behavior and Physical Activity: A Longitudinal Study

ABSTRACT

Despite national interest in leveraging school environments to promote population health, few longitudinal studies have addressed school built environments' relationships to students' physical activity (PA). Most studies of child and youth PA have focused on moderate to vigorous physical activity (MVPA) as the primary outcome, but patterns of sedentary accumulation have also been associated with key health indicators. This study was a natural experiment to determine whether an elementary school environment, intentionally and holistically designed to promote PA, had impact on students' school-time sedentary and PA behaviors. The intervention group in rural Virginia wore accelerometers at time points prior to and 14 months after moving to the newly designed school. Longitudinal accelerometer measures from a socio-demographically similar group at two rural New York State schools served for comparison. To understand involvement of maturation effects, a distinct same-grade group wore accelerometers at the follow-up time point at the intervention school. PA psychosocial measures were also collected pre- and post-occupancy from a longitudinal intervention group. Results were as follows, based on models adjusting for gender and race/ethnicity: There was a downward, but non-significant ($p=0.3056$), trend in daily sedentary time in the longitudinal intervention group, as compared to a significant increase in sedentary time in the longitudinal comparison group, and 3rd graders in the new school environment spent less time sedentary as compared to their counterparts in the previous environment ($p<0.0001$). There were indicators that the new school environment had a positive effect on sedentary accumulation patterns. In the longitudinal intervention group, there were decreases in lengths of sedentary bouts ($p<0.0001$) and breaks ($p<0.0001$), and an increase in number of daily breaks from sedentary behavior ($p<0.0001$). The trends were reversed in the comparison group, with increases in lengths of sedentary bouts

(*p*<0.0001) and breaks (*p*=0.0210), and fewer daily breaks from sedentary behavior (*p*=0.0015). Third graders in the new school environment had shorter bouts (*p*<0.0001) and breaks (*p*<0.0221), and more daily breaks from sedentary behavior (*p*<0.0001), as compared to their same-grade counterparts in the previous environment. There was a non-significant increase in daily time in light physical activity (LPA) among the intervention group (*p*=0.1377), while LPA time decreased among the comparison group (*p*=0.0001). Third graders in the new school environment spent more time in LPA (*p*=0.0001) than their counterparts in the previous environment. The global PA measure, steps per minute, decreased similarly in the intervention (*p*=0.0261) and comparison (*p*=0.0275) groups, and steps per minute were equivalent in the independent same-grade groups (*p*=0.6405). MVPA decreased substantially in the longitudinal intervention group (*p*<0.0001), while a non-significant decrease occurred in the comparison group (*p*=0.2124). Based upon sedentary and light PA behavior results, active classroom design strategies likely were effective in nudging children to move more during lesson times. At the same time, the new school's longer interior walking distances – a consequence of the pre-determined site and existing structures – to locations where higher levels of PA were condoned could have resulted in replacement of potential MVPA with LPA. For design practitioners, these results point to active classroom design strategies including dynamic furnishings and quick access to areas permissive of high intensity activities. School designers may also wish to delineate within-school travel distances in consideration of the categories of PA condoned by policy and social norms in various school locations by age groups. Future hypothesis-driven studies of school environments and PA outcomes may well focus on both sedentary and PA accumulation, incorporating objective spatial relationships in building and site programs and measures of activity social norms and policies in the building and site programmatic areas.

BACKGROUND

It has been well established that children's time spent in and intensity levels of physical activity (PA) have profound impact on their current and future health, including obesity and related diseases, and cardiovascular risk [4]. Multiple studies have shown that PA tends to decrease over time in children both prior to and during adolescence, with negative health consequences [191-197]. Research has also revealed that children were sedentary during 70% of class time in school, including physical education class, and that the majority of children also remained sedentary during breaks and lunchtime [56]. Children spend a large proportion of their waking hours in school, and schools are relatively accessible, as compared to home and neighborhood environments, to population-based interventions [55]. Therefore, increasing children's PA at school has become a national focus to address the problems of childhood obesity and related diseases, and emphasis has been placed on the need to develop further high-quality research on the influence of school environments on children's PA [4].

Moderate to vigorous physical activity (MVPA) has clinical relevance given the U.S. recommendation that children spend a minimum total of 60 minutes per day in MVPA [7-9], and its correlations with weight status have been well established [198]. MVPA is a combination of two categories of activity intensity: Moderate physical activity (MPA) increases the heart rate above resting level and includes such activities as brisk walking and gardening, and vigorous physical activity (VPA) includes activities such as running and fast swimming [199]. Light physical activity (LPA) includes such activities as leisurely walking and stretching, while sedentary behavior refers to waking activities that do not increase energy expenditure substantially above the resting level [39].

Although much of the evidence pertaining to children's PA, weight status and cardio-metabolic health has focused on MVPA, a number of studies have addressed sedentary behavior as well. A systematic review of studies of children suggested that reductions in any type of sedentary time correlated to lower health risk [200], and both cross-sectional [201,202] and longitudinal [203,204] studies have supported this notion. Independent of total sedentary time and time in MVPA, a higher number of breaks and variations in sedentary behavior has been positively associated with lower waist circumference and lower body mass index [39]. Among a sample of 11-14 year old Canadian boys, each additional 60 minutes of daily sedentary time was associated with 1.4 kg/m^2 higher BMI and 3.4 cm higher waist circumference [205]. In addition, research has shown that increases in non-exercise activity thermogenesis (NEAT), a product of such activities as fidgeting and standing, impacted overall energy balance and provided protection against fat gain and obesity [37,40-42]. In some studies of children, time in and frequency of sedentary behavior were not independently associated with adiposity [198] or cardio-metabolic risk factors [206], however, and some researchers have noted that hypotheses of causal associations between sedentary behavior and such health indicators have yet to be definitively demonstrated in young populations [207]. For example, one large study found that sedentary behavior was positively associated with obesity, but not independently of MVPA [208].

Among studies of school built environment characteristics and child and youth PA, outcomes of focus have included MVPA, measured either with accelerometers or with an observational method, and other accelerometer-measured outcomes such as steps per minute [209]. Some studies have used other devices and measures, including time in sedentary behavior. Despite theoretical support and evidence of associations between aspects of school environmental design and students' physical activity, there have been few longitudinal studies that address the question as to whether a school environment, or features of the environment, designed to increase PA actually had the intended impacts. Among longitudinal studies, cluster randomized controlled trials (RCT) found that use of newly installed school gardens had positive impact on school-time MVPA [64], and that a playground intervention with color-coded zones produced greater numbers of physically active children vs. control playgrounds [82,83]. A large European cluster RCT found that a multi-component school intervention focused mainly on outdoor and recess areas, improving the environment for active commuting, and PA programs had only very limited school-time impact [169]. A small cluster RCT, one of few studies focused on the influence of school interiors on PA, showed lower frequency and duration of static sitting in a classroom outfitted with stand-biased desks vs. conventional furnishings [142]. And, small longitudinal studies addressed the PA differences between movement-promoting classrooms and furnishings vs. traditional classrooms with rows of conventional rigid chairs and desks, and found that the movement-promoting environments produced higher levels of PA measured as acceleration [140], and greater caloric expenditure measured with an armband device [142].

This study adds to the limited body of longitudinally-derived evidence about the impact of school environments on students' PA and sedentary behavior. We undertook a natural experiment opportunity in collaboration with school designers and administrators of the Carter G. Woodson Education Complex, a primary and elementary school in Buckingham County, Virginia. A new school was holistically designed and constructed to promote PA and health, drawing upon the *Physical Activity Design Guidelines for School Architecture* [209] presented in Chapter 1.

The overarching aim of this study was to test the central hypothesis that an elementary school built environment, intentionally and holistically designed to promote PA, would have significant positive effects on students' school-time PA and sedentary behavior outcomes. Specific hypotheses were as follows:

1. The activity promoting school environment would have a positive impact on sedentary behavior, demonstrated by:
    a. A decrease or reduced maturational increase in daily sedentary time among the longitudinal intervention group, in contrast with expected maturational increase in daily sedentary time among the longitudinal comparison group, and an increase in frequency of transitions between sedentary behavior and LPA among the longitudinal intervention group, in contrast with expected consistency or decrease in these measures among the longitudinal comparison group, demonstrated by shorter sedentary bouts and breaks, and an increase in the number of daily breaks from sedentary behavior.
    b. Less daily sedentary time among the 3rd graders in the intervention school environment as compared to an independent sample of 3rd graders in the previous school environment, and higher frequency of transitions to and from sedentary behavior and light PA among 3rd graders in the intervention school environment as compared to an independent sample of 3rd graders in the previous school environment, demonstrated by shorter sedentary bouts and breaks, and a higher number of daily breaks from sedentary behavior.
2. The activity promoting school environment would either cause an increase or mitigate maturational decrease in daily time in LPA, as demonstrated by:
    a. An increase or reduced maturational decrease in daily time in LPA among the longitudinal intervention group, in contrast with expected maturational decrease among the longitudinal comparison group.

b. More daily time in LPA among the 3rd graders in the intervention school environment, as compared to time in LPA among an independent sample of 3rd graders in the previous school environment.

3. The activity promoting school environment would have a positive effect on PA overall, measured as steps per minute, demonstrated by:
   a. An increase or reduced maturational decrease in steps per minute among the longitudinal intervention group, in contrast with expected maturational decrease in steps per minute among the longitudinal comparison group.
   b. Higher steps per minute among the 3rd graders in the intervention school environment, as compared to steps per minute in an independent sample of 3rd graders in the previous school environment.
4. The new school environment would cause an increase or reduce maturational decrease in daily time in MVPA, as demonstrated by:
   a. An increase or reduced maturational decrease in daily time in MVPA among the longitudinal intervention group, in contrast with expected maturational decrease among the longitudinal comparison group.
   b. More daily time in MVPA among the 3rd graders in the intervention school environment, as compared to time in MVPA among an independent sample of 3rd graders in the previous school environment.
5. The new school environment would positively impact PA psychosocial outcomes of social support and self-efficacy, as demonstrated by changes in these measures among a longitudinal intervention group.

METHODS

Environmental Intervention

In Buckingham County, Virginia, the aging primary and elementary school buildings and sites lacked gymnasiums or other indoor PA-dedicated facilities, and were too small to accommodate the student population, with temporary trailers added to supplement classroom space. The newly designed school was much larger, with complete renovations of two distinct previously vacant facilities at a nearby rural site, as well as new construction to connect and integrate these existing facilities. Where possible, design decisions drew upon the *Physical Activity Design Guidelines for School Architecture* [209]. Since the new school site had been pre-determined by the school district, site selection strategies in the 1st design domain (Table 1.2) were for the most part not relevant to the project, and the rural, low population density location and long home-to-school distances precluded focus on encouraging active commuting to and from school. Future-oriented strategies in the 10th domain (Table 1.2), pertaining to mobile technologies and virtual environments, were also not pursued in this project.

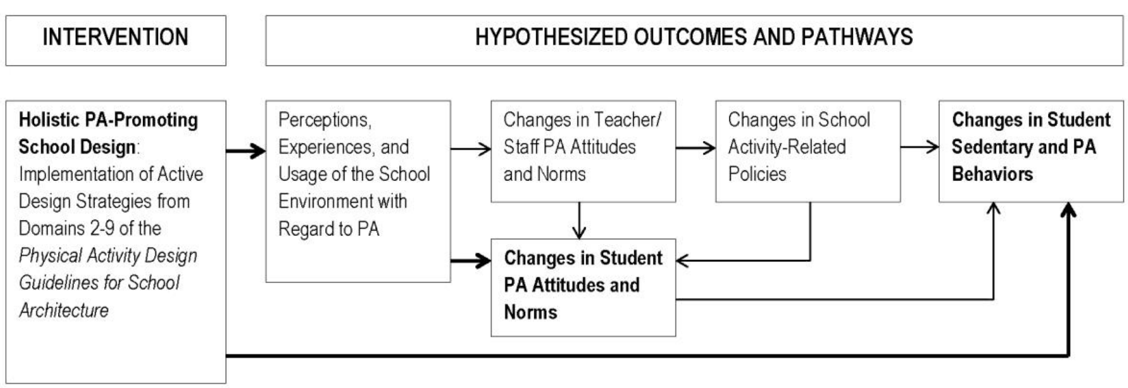
Architects and designers did engage the other 8 domains (Table 1.2) in their work on the new school. In consideration of the existing buildings on the site, the new construction and connections were scaled with children in mind and conceived to maximize outdoor views and natural light. Outdoor spaces formed by the building massing included a courtyard with pathways under a 2nd floor bridge to outdoor activity areas, and an outdoor classroom and gardens to promote higher levels of activity during lesson times. Adjacencies were intended to encourage use of these new program areas, such as vegetable garden adjacency to the outdoor classroom, dining commons and commercial kitchen (Figure 1.14). The dining commons was located in the central area of new construction, intended to promote walking to and from classroom locations during the school day. In order to promote MVPA, the program included two large indoor fitness areas: a flexible, bright space with multi-use painted floor markings in the primary school wing, and in the elementary school a more traditional gymnasium with original maple flooring and court markings that had been part of the existing facility. In both areas, interior glazing was added, so that students passing in the hallway could observe others engaging in PA (Figure 1.10). Also in support of MVPA, the large site included two playgrounds and two large sports fields, as well as nature trails, areas with edible plants, and a “frog bog” pond and small stream for exploration and active teaching opportunities (Figure 1.4).

In order to encourage movement and breaks from sedentary behavior, as well as to promote light PA, classrooms were amply sized, and all classroom and lab spaces outfitted with mobile and dynamic furnishings. These moveable and adjustable furnishings, such as chairs that tip, rock, and accommodate forward- or backward-facing sitting positions, were intended to facilitate children’s natural inclinations for movement and to discourage long bouts of static sitting (Figures 1.9 and 1.16). All classrooms, as well as outdoor play areas and gardens, included drinking fountains. A monumental staircase of local slate material was placed centrally in the community area of the new construction (Figure 1.5), and all stairways were renovated to be bright and open-feeling. In hallways, animal footprints were imbedded in the terrazzo flooring for children to follow, as part of the eco-themed wayfinding system (Figure 1.18), and educational and motivational point-of-prompt signage encouraged physical activity and healthy behaviors (Figure 1.17). Other ‘movement temptations’ included the Tree Canopy to climb over and through at an intersection of hallways and lab areas in the Primary School wing (Figure 1.6).

Conceptual/Logic Model

The logic model for the study drew upon ecological [210,211], social cognitive [24], and person-environment interaction [22] theories, positing that changes to the school environment may have both indirect (via changes in social norms, perceptions and attitudes) and direct effects on student's PA behaviors (Figure 2.1). This study focused on objective accelerometer measures of changes in student activity-related behaviors, and changes in student PA attitudes and social support based upon psychometric survey measures. To date, no substantial changes in PA school policies have been documented, and student perceptions of the environment and teacher/staff healthy behavior norms are being addressed in separate papers [212,213]. Notably, a longitudinal qualitative analysis of student drawings of the previous and new school environments indicated a several month time lag in conceptualizing the new school environment; revealed student perceptions that the new school was very large and somewhat overwhelming at first; pointed to perceived connections of social engagement with PA; and revealed children's drawn reflections of prominent visual cues in the environment [212].

Figure 2.1. Logic Model of School Design Intervention and Physical Activity Behaviors. Bold arrows and text indicate the pathways and measures of focus in this study.



Research Design and Sampling

The research design included both longitudinal and cross-sectional components. The longitudinal portion of the study included an intervention group and a demographically similar comparison group. The cross-sectional component compared same-grade groups at two points in time in different school environments.

Occupancy of the new PA-promoting Virginia school (the intervention school) occurred in Fall 2012. Data collection in Virginia occurred in the previous school facility in Spring 2012, and after occupancy of the new school in Fall 2013. Data collection at the New York State schools used for comparison occurred in Fall 2011 and Spring 2013, covering an equivalent length of time. Table 2.1 delineates the sample groups and data collection time points.

To test Hypotheses 1-4, data from the longitudinal intervention group (2nd semester 3rd graders), from one arbitrarily selected classroom, were collected in Spring 2012 at a Buckingham County elementary school facility that was subsequently closed, and again 14 months post-occupancy (as 5th graders, in 3 classrooms, n=21) at the newly-opened Carter G. Woodson Education Complex. Data from the longitudinal comparison group (1st semester 4th grade students, n=32) at two rural New York State schools were collected by Cornell University researchers in Fall 2011, and again as 5th graders (n=20) in Spring 2013 at the same schools, which were aging facilities that did not undergo any improvements or renovations (Table 2.2). In addition, accelerometry data were collected from an independent sample of 3rd graders, in an arbitrarily selected classroom in the new Virginia school environment (Table 2.2).

The longitudinal intervention and comparison groups both resided in rural areas, and were demographically similar. Although there were somewhat higher proportions of racial/ethnic minorities and free and reduced price meal (FRPM) program eligibility at the

Table 2.1. Research Design: Samples and Timeline.

	Student Groups	Fall 2011	Spring 2012	Semester Fall 2012	Spring 2013	Fall 2013
CROSS-SECTIONAL SAMPLES						
Intervention School (Virginia)	3rd Graders (2nd Semester), Ages 8-9		Data Collection at Previous School (May 28–Jun 1)			
	3rd Graders (1st Semester), Ages 8-9					Data Collection at New School (Oct 17–23)
LONGITUDINAL SAMPLES						
Intervention School (Virginia)	3rd Graders (2nd Semester), Ages 8-9		Baseline Data Collection at Previous School (May 28–Jun 1) →			
	5th Graders (1st Semester), Ages 10 -11					Follow-Up Data Collection at New School (Oct 17–23)
Non-Intervention Comparison Schools (New York State)	4th Graders (1st Semester), Ages 8-9	Baseline Data Collection at 2 Schools (Oct 4–Nov 10) →				
	5th Graders (2nd Semester), Ages 10-11				Follow-Up Data Collection at Same 2 Schools (May 13–30)	

intervention school, both the intervention and comparison school populations included substantial numbers of minority students, and a minimum of 55% of all students eligible for FRPM (Table 2.2).

Table 2.2. Demographics of Intervention and Comparison Schools.

School Groups	% FRPM Eligible at School*	% Racial/Ethnic Minority at School	Local Population (2013) In Town or Village	Local Population (2013) In County
Intervention School				
Buckingham County Elementary School, Dillwyn, VA	74%	45%	451[1]	17,200[2]
Comparison Schools				
Margaretville Central School, Margaretville, NY	55%	26%	589[3]	46,722
Kelley Elementary School, Newark, NY	56%	23%	8,952[3]	92,473

For Hypotheses 1-4, the significances of changes in accelerometer-measured outcomes over the study time period were compared between the longitudinal intervention and comparison groups. In addition, differences in measures among independent same-grade groups were assessed. To test Hypotheses 5, survey-based psychosocial data were collected among a longitudinal intervention group in Virginia in Spring 2012 and Fall 2013, and changes in scale measures over the study time period assessed.

Accelerometry

Protocols

Virginia school children wore accelerometers on a belt around the waist, positioned at the right hip bone, for 5-7 consecutive day periods at two time points, pre- and post-occupancy of the new school facility. Each participant wore either the ActiGraph GT3X+ or GT1M accelerometer model. Students and parents were provided detailed instructions for wearing the accelerometers at all times, except for sleeping and bathing. New York State school children also wore ActiGraph accelerometers on a belt around the waist, positioned at the right hip, as described elsewhere [64]. These students wore accelerometers only during the school day.

Accelerometry Data Processing

The investigator engaged in accepted practice for accelerometry data processing and scoring [214], using ActiLife v.6.11.7 software (ActiGraph Corporation, Pensacola, FL). Non-wear time was defined as 30 consecutive minutes of zero activity counts, and age-based sedentary behavior and light, moderate, and vigorous activity cut points for children were based on Evenson et al. (2008) [215,216]. As this study addressed only school time, definition of a valid day was set to and limited by the length of the school day for each group. For all groups, the minimum number of valid wear days was 3, although the Virginia school groups included some subjects with 4-5 valid wear days. In New York State, students wore accelerometers for 3 days. Filters were set for school days and school hours for each school set of raw data. Prior to scoring, all data were reintegrated to 60-second epochs, the minimum possible epoch length to encompass raw data including 10-, 30-, and 60-second epoch lengths. The potential impacts of epoch length choices have been discussed in the literature [214,217]: Activity counts are integrated and recorded in longer time durations with larger epoch lengths. Therefore, comparisons of higher levels of activity across studies should take into account that longer epoch lengths may not fully capture quick spikes and variations in children's activity, thereby leading to under-estimation of MVPA [214]. However, some evidence regarding such potential bias has been contradictory [218]. Sixty second epoch lengths have been most common in the literature [214], although there has been a recent trend toward shorter epoch lengths in studies of children.

Accelerometry Measures

Outcome measures scored from raw accelerometry data were as follows:

- Number of daily sedentary bouts (an indicator of sedentary behavior accumulation pattern)
- Average length of sedentary bout (an indicator of sedentary behavior accumulation pattern)
- Daily number of breaks from sedentary behavior (an indicator of sedentary behavior accumulation pattern)
- Average length of breaks from sedentary behavior (an indicator of sedentary behavior accumulation pattern)
- Daily total time in sedentary behavior

- Daily total time in LPA
- Steps per minute (a "global" measure of PA)
- Daily total time in MVPA.

For the purpose of between group comparisons, daily measures were imputed for consistent length of school day (7 hours).

Statistical Analysis

Adequate distributional normality of variables and variable transformations, as warranted, were confirmed, and baseline and follow-up longitudinal (within-subject) measures compared using paired t-tests. Then, linear mixed models controlled for gender and race/ethnicity, and tested for interaction effects. For the cross-sectional samples, once adequate distributional normality was confirmed, analyses included independent samples t-tests, and then linear mixed models controlling for gender and race/ethnicity. Statistical analyses were performed using SAS v.14 software (SAS Institute, Cary, NC).

Survey

Sampling and Data Collection

Participants were a longitudinal cohort of 3rd grade students who progressed to 5th grade in the rural Virginia location only. Baseline measures were collected in Spring 2012 in the previous school environment, and follow-up measures collected in Fall 2013 in the new activity-promoting (intervention) school environment.

Measures

Psychosocial measures related to PA were drawn from the Child and Adolescent Trial for Cardiovascular Health (CATCH), and the Health Behavior Questionnaire (HBQ), previously shown to be valid and reliable [219,220]. The scales assessed children's perceived social reinforcement of PA among family members, teacher, and friends, and children's PA self-efficacy, or confidence in ability to participate in age-appropriate physical activities. Perceived positive reinforcement of PA was an 11-item scale (Cronbach's α = 0.67-0.68), and perceived negative reinforcement of PA was a 7-item scale (Cronbach's α = 0.56-0.60). PA self-efficacy was a 5-item scale (Cronbach's α = 0.67-0.69).

Statistical Analysis

As the scale variable distributions were highly skewed, the Wilcoxon Signed Ranks test was used initially to assess within-subject change over time. Further analyses used generalized linear mixed models to control for gender and race/ethnicity and to test for interaction effects. Survey data analyses were conducted with SAS v.14 software (SAS Institute, Cary, NC).

Human Subjects Review

The Institutional Review Boards (IRB) of the University of Virginia and the University of Nebraska Medical Center approved the research protocol for the Virginia student samples. Parents provided signed informed consent, and students provided verbal asset for participation. For the New York State student samples, the Cornell University IRB deemed the protocol exempt, as reported elsewhere [64].

RESULTS

Accelerometry (Hypotheses 1-4)

Sample Demographics

There was similar loss to follow-up in both the intervention and comparison groups, primarily due to students' moves to other locales and schools. In the Virginia sample, one device was returned by a student long after data collection concluded, and by that time contained no usable data due to battery depletion. Due to the arbitrary classroom selection, the baseline Virginia sample of 3rd graders was weighted toward males, but the gender distribution was more equally split at follow-up, and was similar to gender distribution in the New York State comparison sample. Age ranges were similar between the groups, despite a one semester (~3 month) offset in data collection timing. Specific birth dates were not available at some schools, and therefore age ranges have been reported in whole years. There was a higher prevalence of minority, in particular African American, students in the Virginia sample, but minority students were also represented in the New York State sample. Sample demographics by data collection timing and group are shown in Tables 2.3 and 2.4.

Table 2.3. Intervention Group (Virginia School) Demographics.

Data Collection Groups and Timing	**N**	**Age** Years (% N)	**Gender** Female	Male	**Race/Ethnicity** White, Non-Hispanic	Black, African-American	Hispanic/ Latino	Other, Mixed Race	Not Reported
Pre-Occupancy Spring 2012 – 3rd Grade (2nd Semester)									
Total 3rd Grade (VA)	32	8 (15%) 9 (85%)	10 (31.3%)	22 (68.7%)	13 (40.6%)	14 (43.8%)	1 (3.1%)	1 (3.1%)	0 (0.0%)
Post-Occupancy Fall 2013 – 5th Grade and 3rd Grade (1st Semester)									
Total 5th Grade (VA)[1]	21	10 (81%) 11 (19%)	6 (28.6%)	15 (71.4%)	10 (47.6%)	10 (47.6%)	1 (4.8%)	0 (0.0%)	0 (0.0%)
Total 3rd Grade (VA)[2]	21	8 (100%)	11 (52.4%)	10 (47.6%)	13 (61.9%)	4 (19.0%)	0 (0.0%)	0 (0.0%)	7 (33.3%)

[1] Longitudinal sample was a subset of the pre-occupancy/baseline sample, as there was loss to follow-up.
[2] Independent cross-sectional sample of 3rd graders.

Table 2.4. Non-Intervention Comparison Group (New York State Schools) Demographics.

Data Collection Location, Timing, Group	**N**	**Age** Years (% N)	**Gender** Female	Male	**Race/Ethnicity** White, Non-Hispanic	Black, African-American	Hispanic/ Latino	Other, Mixed Race	Not Reported
Fall 2011 – 4th Grade (1st Semester)									
Margaretville, NY	12	9 (100%)	5 (41.7%)	7 (58.3%)	11 (91.7%)	0 (0.0%)	1 (8.3%)	0 (0.0%)	0 (0.0%)
Newark, NY	20	8 (17%) 9 (83%)	12 (60.0%)	8 (40.0%)	14 (70.0%)	4 (20.0%)	1 (5.0%)	0 (0.0%)	1 (5.0%)
Total 4th Grade (NY)	32	8 (9%) 9 (91%)	17 (53.1%)	15 (46.9%)	25 (78.1%)	4 (12.5%)	2 (6.3%)	0 (0.0%)	1 (3.1%)
Spring 2013 – 5th Grade (2nd Semester)									
Margaretville, NY	11	10 (33%) 11 (67%)	4 (36.4%)	7 (63.6%)	10 (90.9%)	0 (0.0%)	1 (9.1%)	0 (0.0%)	0 (0.0%)
Newark, NY	9	10 (22%) 11 (78%)	7 (77.8%)	2 (22.2%)	6 (66.7%)	2 (22.2%)	1 (11.1%)	0 (0.0%)	0 (0.0%)
Total 5th Grade (NY)[1]	20	10 (30%) 11 (70%)	11 (5.50%)	9 (4.50%)	16 (80.0%)	2 (10.0%)	2 (10.0%)	0 (0.0%)	0 (0.0%)

[1] Longitudinal sample was a subset of the baseline sample, as there was loss to follow-up.

Accelerometry Findings

Results from Tests of Hypothesis 1. Analyses confirmed that the activity promoting environment of the new Virginia school had positive impacts on sedentary behavior patterns and total sedentary time accumulation.

Hypotheses 1.a. held true. Daily sedentary time among the intervention group showed a non-significant decrease, in contrast with a significant increase in daily sedentary time among the longitudinal comparison group, indicating that the intervention had a desirable effect in mitigating the typical maturation trend of increasing sedentary behavior over time.

Specifically, in the Virginia longitudinal intervention group at baseline, mean daily time spent sedentary was nearly 259 minutes (Table 2.5), or 62.5% of the school day. At follow-up, average daily time spent sedentary was about 10 minutes less, but the difference was not statistically significant based on analyses that were unadjusted (p=0.3056) (Table 2.5) and adjusted for gender and race/ethnicity (p=0.1541) (Table

2.6). Adjusted analyses revealed no significant gender or race/ethnicity effects at the 95% confidence level, although there was marginal significance (p=0.0711) for higher overall daily sedentary time among Whites as compared to Minorities (Table 2.6). There were no significant interaction effects among variables.

Table 2.5. Unadjusted Longitudinal (Within-Subject) Changes in Daily Sedentary Time.

Outcome Variable and Group	N	Baseline Mean (SD)	Follow-Up Mean (SD)	Mean Difference (SD)	*p*-Value
Daily Time in Sedentary Behavior (mins)[1]					
Intervention Group Total	21	258.44 (44.28)	248.64 (44.10)	-9.80 (42.70)	0.3056
Female	6	280.50 (41.10)	252.78 (39.21)	-27.73 (53.54)	0.2605
Male	15	249.62 (43.66)	246.99 (47.11)	-2.62 (37.25)	0.7888
White, Non-Hispanic	10	277.78 (41.01)	267.85 (36.15)	-9.93 (55.74)	0.5870
Minority[2]	11	240.86 (41.17)	231.19 (44.83)	-9.68 (29.15)	0.2966
Comparison Group Total	20	212.73 (48.36)	251.23 (31.63)	38.49 (43.78)	0.0009
Female	11	219.09 (46.81)	263.75 (28.83)	44.66 (43.49)	0.0067
Male	9	204.96 (51.89)	235.92 (29.29)	30.96 (45.51)	0.0756
White, Non-Hispanic	16	212.94 (48.76)	245.25 (31.97)	32.31 (42.32)	0.0080
Minority[3]	4	211.90 (54.07)	275.13 (16.55)	63.23 (46.50)	0.0726

[1] Outcome variable values imputed for consistent length of school day.
[2] Minority group included 10 Black/African-American students and 1 Hispanic/Latino student.
[3] Minority group included 2 Black/African-American students and 2 Hispanic/Latino students.

Table 2.6. Adjusted Longitudinal (Within-Subject) Changes in Daily Sedentary Time.

Outcome Variable and Group		Model Adjusting for Gender		Model Adjusting for Gender and Race/Ethnicity[3]	
		Parameter Est.[1]	*p*-Value	Parameter Est.[1]	*p*-Value
Daily Time in Sedentary Behavior (mins)[2]					
Intervention Group	Time	-12.78	0.1669	-13.26	0.1541
	Female vs. Male	7.65	0.6068	-8.32	0.6375
	White vs. Minority[3]			31.06	0.0711
Comparison Group	Time	46.61	<0.0001	48.12	<0.0001
	Female vs. Male	11.95	0.3028	10.77	0.3984
	White vs. Minority[3]			-6.58	0.6479

[1] Estimates and *p*-values from linear mixed models of outcome with time, and covariates gender and race/ethnicity, as indicated.
[2] Outcome variable values imputed for consistent length of school day.
[3] Race/Ethnicity a binary variable with values White/Non-Hispanic or Minority (including Black/African-American and Hispanic/Latino students).

By contrast, among children in the New York State longitudinal comparison group, mean daily sedentary time increased by about 38 minutes (Table 2.5) from baseline to follow-up, and this change was significant based upon analyses that were unadjusted (p=0.0009) (Table 2.5) and adjusted for gender and race/ethnicity (p<0.0001)

(Table 2.6). Adjusted analyses revealed no significant gender or race/ethnicity effects (Table 2.6), and there were no significant interaction effects.

In addition, patterns of sedentary accumulation improved in the longitudinal intervention group. There was an increase in frequency of transitions between sedentary behavior and LPA among the intervention group, in contrast with decrease in frequency of transitions among the longitudinal comparison group.

Specifically, in the longitudinal intervention group from baseline to follow-up, the average length of a sedentary bout decreased significantly based on analyses that were unadjusted (p=0.0001) (Table 2.7) and adjusted for gender and race/ethnicity (p<0.0001) (Table 2.8). By contrast, in the longitudinal comparison group, average length of a sedentary bout increased based on unadjusted (p<0.0001) (Table 2.7) and adjusted (p<0.0001) (Table 2.8) analyses. There were no significant gender or race/ethnicity effects (Table 2.8), and no significant interaction effects.

In the longitudinal intervention group, the average length of a break from sedentary behavior decreased from baseline to follow-up based on unadjusted (p<0.0001) (Table 2.7) and adjusted (p<0.0001) (Table2.8) analyses. In the comparison group, the average length of a break from sedentary appeared to hold steady based on unadjusted (p=0.6937) (Table 2.7) analysis, but increased overall (p=0.0210) based on the model controlling for a significant gender*time interaction (p=0.0049) and for race/ethnicity (Table 2.8). In particular, the slope of the trend of sedentary break length over time was lower for females than for males. There were no significant gender effects in the intervention group (p=0.6424), and no significant race/ethnicity effects in the comparison group (p=0.6155) (Table 2.8), although this sample size was small (Table 2.7). In the intervention group, Whites had shorter average breaks from sedentary behavior overall as compared to Minorities (p=0.0282) (Table 2.8).

Table 2.7. Unadjusted Longitudinal (Within-Subject) Change in Sedentary Bout and Break Lengths, and Daily Number of Breaks from Sedentary Behavior.

Outcome Variable and Group	N	Baseline Mean (SD)	Follow-Up Mean (SD)	Mean Difference (SD)	*p*-Value
Average Length of a Sedentary Bout (mins)					
Intervention Group Total	21	8.79 (4.71)	5.38 (1.48)	-0.44 (0.42)[2]	0.0001
Female	6	11.07 (8.03)	5.49 (1.51)	-0.59 (0.62)[2]	0.0690
Male	15	7.87 (2.35)	5.34 (1.52)	-0.39 (0.32)[2]	0.0004
Non-Hispanic	10	10.15 (6.50)	5.97 (1.85)	-0.45 (0.58)[2]	0.0359
Minority[3]	11	7.55 (1.67)	4.85 (0.80)	-0.44 (0.24)[2]	0.0001
Comparison Group Total	20	4.28 (1.29)	6.42 (2.22)	0.40 (0.34)[2]	<0.0001
Female	11	4.50 (1.43)	7.22 (2.59)	0.46 (0.37)[2]	0.0021
Male	9	4.01 (1.12)	5.44 (1.14)	0.32 (0.31)[2]	0.0141
White, Non-Hispanic	16	4.21 (1.07)	6.00 (2.02)	0.34 (0.31)[2]	0.0006
Minority[4]	4	4.56 (2.16)	8.08 (2.45)	0.61 (0.41)[2]	0.0584
Average Length of a Break from Sedentary Behavior (mins)					
Intervention Group Total	21	5.08 (1.50)	3.52 (0.83)	-1.57 (1.04)	<0.0001
Female	6	4.59 (0.53)	3.47 (0.56)	-1.12 (0.59)	0.0057
Male	15	5.28 (1.72)	3.53 (0.93)	-1.74 (1.14)	<0.0001
White, Non-Hispanic	10	4.44 (0.54)	3.22 (0.62)	-1.21 (0.62)	0.0002
Minority[3]	11	5.67 (1.85)	3.78 (0.92)	-1.88 (1.26)	0.0006
Comparison Group Total	20	3.46 (0.72)	3.62 (1.02)	0.03 (0.29)[2]	0.6937
Female	11	3.28 (0.50)	3.03 (0.80)	-0.10 (0.27)[2]	0.3858
Male	9	3.68 (0.90)	4.32 (0.81)	0.18 (0.27)[2]	0.0861
White, Non-Hispanic	16	3.50 (0.77)	3.83 (1.03)	0.08 (0.30)[2]	0.3188
Minority[4]	4	3.31 (0.48)	2.75 (0.19)	-0.18 (0.18)[2]	0.1440
Average Daily Number of Breaks from Sedentary Behavior[1]					
Intervention Group Total	21	31.19 (6.79)	46.39 (7.47)	15.20 (9.51)	<0.0001
Female	6	29.75 (9.21)	46.51 (7.26)	16.76 (12.22)	0.0201
Male	15	31.77 (5.85)	46.34 (7.80)	14.57 (8.63)	<0.0001
White, Non-Hispanic	10	30.85 (8.09)	45.96 (8.23)	15.11 (11.75)	0.0028
Minority[3]	11	31.50 (5.74)	46.78 (7.09)	15.28 (7.52)	<0.0001
Comparison Group Total	20	49.41 (6.30)	40.42 (8.24)	-8.99 (8.94)	0.0002
Female	11	48.88 (6.73)	38.41 (9.64)	-10.48 (8.50)	0.0021
Male	9	50.06 (6.06)	42.89 (5.72)	-7.17 (9.62)	0.0559
White, Non-Hispanic	16	49.55 (4.88)	41.73 (7.42)	-7.83 (9.08)	0.0036
Minority[4]	4	48.85 (11.46)	35.20 (10.45)	-13.65 (7.58)	0.0368

[1] Outcome values adjusted for consistent length of school day.
[2] Based on natural log variable transformation.
[3] Minority group included 10 Black/African-American students and 1 Hispanic/Latino student.
[4] Minority group included included 2 Black/African-American students and 2 Hispanic/Latino students.

In the intervention group, the number of daily breaks from sedentary behavior increased over time based on analyses that were unadjusted (p<0.0001) (Table 2.7) and adjusted for gender and race/ethnicity (p<0.0001) (Table 2.8). In the comparison group, the number of daily breaks from sedentary behavior decreased over time based on unadjusted (*p*=0.0002) (Table 2.7) and adjusted (for gender and race/ethnicity) (*p*=0.0015) analyses (Table 2.8). There were no significant gender or race/ethnicity effects in either group (Table 2.8), and no significant interaction effects.

Table 2.8. Adjusted Longitudinal (Within-Subject) Change in Sedentary Bout and Break Lengths, and Daily Number of Breaks from Sedentary Behavior.

Outcome Variable		**Model Adjusting for Gender**		**Model Adjusting for Gender and Race/Ethnicity**	
		Parameter Est.[1]	***p*-Value**	**Parameter Est.**[1]	***p*-Value**
Average Length of a Sedentary Bout					
Intervention Group	Time	-0.49	<0.0001	-0.49[3]	<0.0001
	Female vs. Male	0.04	0.6997	-0.06[3]	0.5822
	White vs. Minority[4]			0.18[3]	0.1148
Comparison Group	Time	0.42	<0.0001	0.42[3]	<0.0001
	Female vs. Male	0.08	0.3981	0.05[3]	0.6387
	White vs. Minority[4]			-0.12[3]	0.2535
Average Length of a Break from Sedentary Behavior					
Intervention Group	Time	-1.53	<0.0001	-1.51	<0.0001
	Female vs. Male	-0.32	0.4084	-0.21	0.6424
	White vs. Minority[4]			-0.98	0.0282
Comparison Group	Time	0.22	0.0190	0.23[3]	0.0210
	Female vs. Male	-0.01	0.9098	0.02[3]	0.8514
	Time*Female	-0.36	0.0051	-0.37[3]	0.0049
	White vs. Minority[4]			0.04[3]	0.6155
Average Daily Number of Breaks from Sedentary Behavior[2]					
Intervention Group	Time	15.92	<0.0001	15.55	<0.0001
	Female vs. Male	0.38	0.8676	-0.62	0.8308
	White vs. Minority[4]			1.11	0.6834
Comparison Group	Time	-7.01	0.0027	-7.61	0.0015
	Female vs. Male	-0.32	0.8967	1.10	0.6748
	White vs. Minority[4]			4.68	0.1226

[1] Estimates and *p*-values from linear mixed models of outcome with time, and covariates gender and race/ethnicity, as indicated.
[2] Outcome values adjusted for consistent length of school day.
[3] Based on natural log variable transformation.
[4] Race/Ethnicity a binary variable with values White/Non-Hispanic or Minority (including Black/African-American and Hispanic/Latino students).

<u>Hypothesis 1.b.</u> held true. There was less daily sedentary time among the Virginia 3rd grade sample in the intervention school environment as compared to an independent sample of 3rd graders in the previous Virginia school environment, supporting the notion that the school environment had an impact separate from maturation effect.

Specifically, based upon analyses that were unadjusted (*p*<0.0001) (Table 2.9) and adjusted for gender and race/ethnicity (*p*<0.0001) (Table 2.10), 3rd graders in the new Virginia school environment spent significantly less daily time – about 50 minutes less per mean measures (Table 2.9) – in sedentary behavior than their counterparts in the previous school environment. There were no significant gender or race/ethnicity effects (Table 2.10), and no significant interaction effects.

Table 2.9. Unadjusted Same-Grade Independent Samples Differences in Daily Sedentary Time.

Outcome Variable and Group	N Previous School	Previous School Mean (SD)	N New School	New School Mean (SD)	Mean Difference (SD)	*p*-Value
Daily Time in Sedentary Behavior (mins)						
Independent 3rd Grade Groups	32	265.16 (39.72)	21	214.88 (37.58)	-50.27 (38.90)	<0.0001
Female	10	273.60 (37.05)	11	218.15 (30.36)	-55.5 (33.7)	0.0013
Male	22	261.32 (41.13)	10	211.29 (45.69)	50.03 (42.55)	0.0044
White, Non-Hispanic	13	276.60 (38.37)	10	211.63 (46.45)	-64.97 (42.02)	0.0014
Minority[1]	16	252.56 (40.52)	4	193.65 (28.88)	-58.91 (38.82)	0.0142

[1] Minority group included Black/African-American and Hispanic/Latino students.

Table 2.10. Adjusted Same-Grade Independent Samples Differences in Daily Sedentary Time.

Outcome Variable and Groups		Model Controlling for Gender		Model Controlling for Gender and Race/Ethnicity[2]	
		Parameter Est.[1]	*p*-Value	Parameter Est.[1]	*p*-Value
Daily Time in Sedentary Behavior (mins)[2]					
Independent 3rd Grade Groups	New vs. Old School	-52.37	<0.0001	-64.06	<0.0001
	Female vs. Male	9.93	0.3792	8.38	0.5331
	White vs. Minority[3]			19.97	0.1410

[1] Estimates from and *p*-values from linear models of outcome with group and gender; and group, gender and race/ethnicity; as indicated.
[2] Outcome variable values imputed for consistent length of school day.
[3] Race/ethnicity a binary variable with values White/Non-Hispanic or Minority (including Black/African-American and Hispanic/Latino students).

As for patterns of sedentary behavior accumulation, there was a higher frequency of transitions between sedentary behavior and LPA among the 3rd graders in the intervention school group, as compared to frequency of transitions among an independent sample of 3rd graders in the previous school environment.

The average length of a sedentary bout was significantly lower among the 3rd graders in the new environment as compared to their counterparts in the previous environment based upon analyses that were unadjusted ($p<0.0001$) (Table 2.11) and adjusted for gender and race/ethnicity ($p<0.0001$) (Table 2.12). There were no significant gender or race/ethnicity effects (Table 2.12), and no significant interaction effects.

The average length of a break from sedentary behavior was also lower in the new vs. old school group based on unadjusted (*p*=0.0011) (Table 2.11) and adjusted (*p*<0.0001) (Table 2.12) analyses. Again there were no significant gender or race/ethnicity effects (Table 2.12), and no significant interaction effects.

The mean daily number of breaks from sedentary behavior was higher among 3rd graders in the new school as compared to the previous school based on unadjusted (*p*<0.0001) (Table 2.11) and adjusted (*p*=0.0221) (Table 2.12) analyses. Overall, White children exhibited a lower number of daily breaks from sedentary behavior as compared to Minority children (*p*=0.0184) (Table 2.12). There were no significant interaction effects.

Table 2.11. Unadjusted Same-Grade Independent Samples Differences in Lengths of Sedentary Bouts and Breaks, and Number of Breaks from Sedentary Behavior.

Outcome Variable and Group	N Previous School	Previous School Mean (SD)	N New School	New School Mean (SD)	Mean Difference (SD)	*p*-Value
Average Length of a Sedentary Bout (mins)						
Independent 3rd Grade Groups	32	9.17 (4.20)	21	4.37 (1.03)	-0.70 (0.31)[1]	<0.0001
Female	10	9.98 (4.5)	11	4.50 (1.05)	-0.71 (0.35)[1]	0.0002
Male	22	8.80 (2.92)	10	4.24 (1.05)	-0.72 (0.28)[1]	<0.0001
White, Non-Hispanic	13	9.72 (5.83)	10	4.11 (0.86)	-0.78 (0.36)[1]	<0.0001
Minority[1]	16	8.49 (2.68)	4	3.70 (1.03)	-0.83 (0.28)[1]	<0.0001
Average Length of a Break from Sedentary Behavior (mins)						
Independent 3rd Grade Groups	32	4.99 (1.26)	21	3.94 (0.69)	-1.05 (1.07)	0.0011
Female	10	4.64 (0.57)	11	3.98 (0.56)	-0.67 (0.56)	0.0141
Male	22	5.18 (1.45)	10	3.91 (0.85)	-1.24 (1.30)	0.0183
White, Non-Hispanic	13	4.38 (0.48)	10	3.70 (0.85)	-0.69 (0.66)	0.0228
Minority[1]	16	5.50 (1.57)	4	4.18 (0.25)	-1.32 (1.44)	0.1181
Average Daily Number of Breaks from Sedentary Behavior						
Independent 3rd Grade Groups	32	30.35 (6.59)	21	48.97 (5.64)	18.62 (6.23)	<0.0001
Female	10	30.58 (7.78)	11	48.67 (6.86)	18.10 (7.31)	<0.0001
Male	22	30.25 (6.17)	10	49.30 (4.26)	19.05 (5.66)	<0.0001
White, Non-Hispanic	13	31.50 (7.75)	10	50.32 (2.64)	18.82 (6.11)	<0.0001
Minority[1]	16	30.03 (5.94)	4	53.00 (8.09)	22.97 (6.35)	<0.0001

[1] Minority group included Black/African-American and Hispanic/Latino students.

Table 2.12. Adjusted Same-Grade Independent Samples Differences in Lengths of Sedentary Bouts and Breaks, and Number of Breaks from Sedentary Behavior.

Outcome Variable and Groups		Model Controlling for Gender		Model Controlling for Gender and Race/Ethnicity[2]	
		Parameter Est.[1]	*p*-Value	Parameter Est.[1]	*p*-Value
Average Length of a Sedentary Bout (mins)					
Independent 3rd Grade Groups	New vs. Old School	-0.71[1]	<0.0001	-0.80[1]	<0.0001
	Female vs. Male	0.06[1]	0.4988	0.06[1]	0.5532
	White vs. Minority[2]			0.06[1]	0.5430
Average Daily Number of Breaks from Sedentary Behavior					
Independent 3rd Grade Groups	New vs. Old School	18.63	<0.0001	20.33	<0.0001
	Female vs. Male	-0.09	0.9626	-0.04	0.9860
	White vs. Minority[2]			0.30	0.8866
Average Length of a Break from Sedentary Behavior (mins)					
Independent 3rd Grade Groups	New vs. Old School	-0.99	0.0023	-0.89	0.0221
	Female vs. Male	-0.26	0.4077	-0.16	0.6519
	White vs. Minority[2]			-0.89	0.0184

[1] Estimates and *p*-values from linear models of outcome with group and gender; and group, gender and race/ethnicity; as indicated.
[2] Race/ethnicity a binary variable with values White/Non-Hispanic or Minority (including Black/African-American and Hispanic/Latino students).

Results from Tests of Hypothesis 2. Analyses showed that the activity promoting intervention school environment had a positive effect on time per school day spent in LPA.

Hypothesis 2.a. held true. Intervention group mean daily time in LPA increased slightly, approximately 8 minutes from baseline to follow-up, but the change was not significant based upon analyses that were unadjusted (p=0.4413) (Table 2.13) and adjusted for gender and race/ethnicity (p=0.1377) (Table 2.14). By contrast, mean daily time in LPA decreased over the study time period by 37 minutes, which was a significant change based upon unadjusted (p=0.0004) (Table 2.13) and adjusted (p=0.0001) (Table 2.14) analyses. At the 95% confidence level, there were no significant gender or race/ethnicity effects in either group (Table 2.14). In the intervention group, however, there was marginally lower (90% confidence level) daily time in LPA overall for White vs. Minority children (Table 2.14).

Table 2.13. Unadjusted Longitudinal (Within-Subject) Change in Daily Time in Light Physical Activity (LPA).

Outcome Variable and Group	N	Baseline Mean (SD)	Follow-Up Mean (SD)	Mean Difference (SD)	*p*-Value
Daily Time in LPA (mins)[1]					
Intervention Group	21	137.44 (37.84)	145.25 (32.75)	7.81 (45.54)	0.4413
Female	6	120.13 (34.77)	148.83 (36.37)	28.71 (51.18)	0.2279
Male	15	144.37 (37.87)	143.82 (32.43)	-0.55 (42.02)	0.9602
White, Non-Hispanic	10	122.18 (36.60)	136.50 (35.17)	14.32 (52.76)	0.4129
Minority[2]	11	151.32 (34.83)	153.20 (29.75)	1.89 (39.52)	0.8774
Comparison Group	20	166.07 (36.40)	129.04 (37.37)	-37.03 (38.35)	0.0004
Female	11	153.05 (33.53)	111.64 (40.87)	-41.42 (40.36)	0.1689
Male	9	181.98 (34.97)	150.30 (17.44)	-31.67 (37.40)	0.0347
White, Non-Hispanic	16	169.08 (36.14)	137.74 (34.20)	-31.34 (36.32)	0.0036
Minority[3]	4	154.02 (40.19)	94.22 (31.24)	-59.80 (43.10)	0.0693

[1] Outcome values imputed for consistent length of school day.
[2] Minority group included 10 Black/African-American students and 1 Hispanic/Latino students.
[3] Minority group included 2 Black/African-American students and 2 Hispanic/Latino students.

Table 2.14. Adjusted Longitudinal (Within-Subject) Daily Time in Light Physical Activity (LPA).

Outcome Variable		Model Adjusting for Gender		Model Adjusting for Gender and Race/Ethnicity	
		Parameter Est.[1]	*p*-Value	Parameter Est.[1]	*p*-Value
Daily Time in LPA (mins)[2]					
Intervention Group	Time	14.14	0.1227	14.08	0.1377
	Female vs. Male	-3.07	0.7864	-8.82	0.5225
	White vs. Minority[3]			-21.64	0.0999
Comparison Group	Time	-35.54	0.0002	-37.38	0.0001
	Female vs. Male	-10.02	0.3199	-10.26	0.3488
	White vs. Minority[3]			6.07	0.6243

[1] Estimates and p-values from linear mixed models of outcome with time and covariates gender and race/ethnicity, as indicated.
[2] Outcome values adjusted for consistent length of school day.
[3] Race/Ethnicity a binary variable with values White/Non-Hispanic or Minority (including Black/African-American and Hispanic/Latino students).

Hypothesis 2.b. held true. There was less daily time in LPA among the Virginia 3rd grade sample in the intervention school environment as compared to the independent sample of 3rd graders in the previous Virginia school environment, supporting the notion that the school environment had an impact distinct from maturation effect.

Specifically, based upon analyses that were unadjusted (p=0.0003) (Table 2.15) and adjusted for gender and race/ethnicity (p=0.0001) (Table 2.16), 3rd graders in the new school environment spent significantly more daily time – 37 minutes more per mean measures (Table 2.15) – in LPA than their counterparts in the previous school environment. There was not a significant gender effect, and White children overall spent marginally less time in LPA as compared to Minorities (*p*=0.0763) (Table 2.16), although non-reported race/ethnicity data in the new school could have impacted this result. There were no significant interaction effects.

Table 2.15. Unadjusted Same-Grade Independent Samples Differences in Daily Time in Light Physical Activity (LPA).

Outcome Variable and Group	N Previous School	Previous School Mean (SD)	N New School	New School Mean (SD)	Mean Difference (SD)	*p*-Value
Daily Time in Light Physical Activity (LPA)						
Independent 3rd Grade Groups	32	129.82 (34.21)	21	167.24 (35.30)	37.42 (34.64)	0.0003
Female	10	123.13 (29.99)	11	166.04 (28.22)	42.9 (29.1)	0.0032
Male	22	132.86 (36.21)	10	168.56 (43.36)	35.70 (38.50)	0.0212
White, Non-Hispanic	13	121.77 (33.75)	10	166.50 (37.64)	-44.73 (35.47)	0.0069
Minority[1]	16	139.73 (35.36)	4	199.65 (29.03)	59.92 (34.38)	0.0060

[1] Minority group included Black/African-American and Hispanic/Latino students.

Table 2.16. Adjusted Same-Grade Independent Samples Differences in Light Physical Activity (LPA).

Outcome Variable and Groups		Model Controlling for Gender		Model Controlling for Gender and Race/Ethnicity[2]	
		Parameter Est.[1]	*p*-Value	Parameter Est.[1]	*p*-Value
Daily Time in Light Physical Activity (LPA)					
Independent 3rd Grade Groups	New vs. Old School	38.82	0.0003	50.92	0.0001
	Female vs. Male	-6.62	0.5116	-4.60	0.6932
	White vs. Minority[2]			-21.01	0.0763

[1] Estimates and *p*-values from linear models of outcome with group and gender; and group, gender and race/ethnicity; as indicated.
[2] Race/ethnicity a binary variable with values White/Non-Hispanic or Minority (including Black/African-American and Hispanic/Latino students).

Results from Tests of Hypothesis 3. Contrary to hypothesis 3, the activity promoting intervention school environment appeared not to have a positive effect on PA overall, based on steps per minute measures.

Hypothesis 3.a. did not hold true. In the longitudinal intervention group, steps per minute decreased based on analyses that were unadjusted (*p*=0.0175) (Table 2.17) and adjusted for gender and race/ethnicity (*p*=0.0261) (Table 2.18). Based on adjusted analysis, steps per minute also decreased in the comparison group, as expected due to maturation (*p*=0.0275) (Table 2.18). In the intervention group, Whites had overall lower steps per minute than minorities (*p*=0.0287) (Table 2.18). In the comparison group, White had marginally higher steps per minute than Minorities (*p*=0.0746), although this sample size was small, and males had marginally higher steps per minute than females (*p*=0.0768) (Table 2.18). There were no significant interaction effects.

Table 2.17 Unadjusted Longitudinal (Within-Subject) Change in Steps per Minute.

Outcome Variable and Group	N	Baseline Mean (SD)	Follow-Up Mean (SD)	Mean Difference (SD)	*p*-Value
Steps per Minute					
Intervention Group Total	21	10.00 (8.34)	8.34 (1.70)	-1.66 (2.93)	0.0175
Female	6	8.5 (3.31)	8.47 (0.82)	-0.03 (3.72)	0.9833
Male	15	10.59 (2.83)	8.29 (1.97)	-2.31 (2.40)	0.0023
White, Non-Hispanic	10	8.91 (3.08)	7.39 (1.58)	-1.52 (3.74)	0.2312
Minority[1]	11	10.98 (2.79)	9.20 (1.35)	-1.78 (2.13)	0.0196
Comparison Group Total	20	9.00 (1.89)	8.17 (3.06)	-0.83 (3.44)	0.2972
Female	11	8.56 (1.46)	6.30 (2.14)	-2.26 (2.93)	0.0285
Male	9	9.53 (2.28)	10.47 (2.41)	0.93 (3.32)	0.4239
White, Non-Hispanic	16	9.06 (2.00)	8.96 (2.82)	-0.11 (3.26)	0.8981
Minority[2]	4	8.75 (1.56)	5.05 (1.80)	-3.70 (2.84)	0.0798

[1] Minority group included 10 Black/African-American students and 1 Hispanic/Latino students.
[2] Minority group included 2 Black/African-American students and 2 Hispanic/Latino students.

Table 2.18. Adjusted Longitudinal (Within-Subject) Change in Steps per Minute.

Outcome Variable		Model Adjusting for Gender		Model Adjusting for Gender and Race/Ethnicity	
		Parameter Est.[1]	*p*-Value	Parameter Est.[1]	*p*-Value
Steps per Minute					
Intervention Group	Time	-1.50	0.0184	-1.44	0.0261
	Female vs. Male	-0.48	0.5567	-0.60	0.5125
	White vs. Minority[2]			-1.95	0.0287
Comparison Group	Time	-1.24	0.0659	-1.46	0.0275
	Female vs. Male	-1.67	0.0165	-1.29	0.0768
	White vs. Minority[2]			1.48	0.0746

[1] Estimates and p-values from linear mixed models of outcome with time and covariates gender and race/ethnicity, as indicated.
[2] Race/Ethnicity a binary variable with values White/Non-Hispanic or Minority (including Black/African-American and Hispanic/Latino students).

Hypothesis 3.b. did not hold true. There was not a significant difference, although the direction was negative, in steps per minute between the Virginia 3rd grade sample in the intervention school environment and the independent sample of 3rd graders in the previous Virginia school environment, based on analyses that were unadjusted (*p*=0.1264) (Table 2.19) and adjusted for gender and race/ethnicity (*p*=0.6405) (Table

2.20). There were no significant gender or race/ethnicity effects (Table 2.20), and no significant interaction effects.

Table 2.19. Unadjusted Same-Grade Independent Samples Differences in Steps per Minute.

Outcome Variable and Group	N Previous School	Previous School Mean (SD)	N New School	New School Mean (SD)	Mean Difference (SD)	*p*-Value
Steps per Minute						
Independent 3rd Grade Groups	32	9.77 (2.77)	21	8.78 (1.13)	-0.99 (2.27)	0.1264
Female	10	9.07 (3.02)	11	8.68 (1.07)	-0.39 (2.22)	0.6935
Male	22	10.09 (2.66)	10	8.88 (1.25)	-1.21 (2.33)	0.1847
White, Non-Hispanic	13	8.95 (8.84)	10	8.84 (1.38)	-0.11 (2.35)	0.9154
Minority[1]	16	10.52 (2.60)	4	9.40 (0.65)	-1.12 (2.39)	0.4127

[1] Minority group included Black/African-American and Hispanic/Latino students.

Table 2.20. Adjusted Same-Grade Independent Samples Differences in Steps per Minute.

Outcome Variable and Groups		Model Controlling for Gender		Model Controlling for Gender and Race/Ethnicity[2]	
		Parameter Est.[1]	*p*-Value	Parameter Est.[1]	*p*-Value
Steps per Minute					
Independent 3rd Grade Groups	Intervention	-0.85	0.1979	-0.38	0.6405
	Female vs. Male	-0.66	0.3154	-0.62	0.4271
	White vs. Minority[2]			-1.11	0.1604

[1] Estimates and *p*-values from linear models of outcome with group and gender; and group, gender and race/ethnicity; as indicated.
[2] Race/ethnicity a binary variable with values White/Non-Hispanic or Minority (including Black/African-American and Hispanic/Latino students).

Results from Hypothesis 4. Contradicting hypothesis 4, analyses showed that the activity promoting intervention school environment had a negative effect on school time per day spent in MVPA.

Hypothesis 4.a. did not hold true. In the intervention group, average daily time spent in MVPA decreased by more than 12 minutes over the study time period, which was significant based upon analyses that were unadjusted ($p<0.0001$) (Table 2.21) and adjusted for gender and race/ethnicity ($p<0.0001$) (Table 2.22). In the comparison group, there was a slight, but non-significant, decrease in MVPA over time based on unadjusted ($p=0.4904$) (Table 2.21) and adjusted ($p=0.2124$) analyses (Table 2.22). There were no significant interaction effects, but some overall differences in MVPA based upon race/ethnicity in the intervention group, and based upon gender in the comparison group (Table 2.22).

Table 2.21. Unadjusted Longitudinal (Within-Subject) Change in Daily Time in Moderate to Vigorous Physical Activity (MVPA).

Outcome Variable and Group	N	Baseline Mean (SD)	Follow-Up Mean (SD)	Mean Difference (SD)	*p*-Value
Daily Time in MVPA (mins)[1]					
Intervention Group Total	21	24.12 (10.06)	12.47 (6.25)	-11.65 (8.72)	<0.0001
Female	6	19.38 (8.20)	10.83 (3.24)	-8.55 (8.20)	0.0510
Male	15	26.02 (10.35)	13.12 (7.22)	-12.89 (8.86)	<0.0001
White, Non-Hispanic	10	20.05 (7.20)	8.10 (4.84)	-11.96 (7.91)	0.0010
Minority[2]	11	27.82 (11.15)	16.44 (4.79)	-11.38 (9.78)	0.0032
Comparison Group Total	20	14.20 (7.52)	12.74 (10.01)	-1.46 (9.28)	0.4904
Female	11	9.67 (3.67)	6.43 (3.58)	-3.24 (4.80)	0.0488
Male	9	19.73 (7.59)	20.44 (10.03)	0.72 (12.90)	0.8714
White, Non-Hispanic	16	15.48 (7.80)	14.51 (10.38)	-0.97 (10.21)	0.7103
Minority[3]	4	9.08 (3.24)	5.65 (3.62)	-3.43 (4.24)	0.2034

[1] Outcome values imputed for consistent length of school day.
[2] Minority group included 10 Black/African-American students and 1 Hispanic/Latino students.
[3] Minority group included 2 Black/African-American students and 2 Hispanic/Latino students.

Table 2.22. Adjusted Longitudinal (Within-Subject) Daily Time in Moderate to Vigorous Physical Activity (MVPA).

Outcome Variable		Model Adjusting for Gender		Model Adjusting for Gender and Race/Ethnicity	
		Parameter Est.[1]	*p*-Value	Parameter Est.[1]	*p*-Value
Daily Time in MVPA (mins)[2]					
Intervention Group	Time	-12.16	<0.0001	-11.97	<0.0001
	Female vs. Male	1.79	0.5457	-2.81	0.3666
	White vs. Minority[3]			-8.22	0.0082
Comparison Group	Time	-2.29	0.1940	-2.27	0.2124
	Female vs. Male	-7.03	0.0012[6]	-7.72	0.0012
	White vs. Minority[3]			-1.26	0.6246

[1] Estimates and *p*-values from linear mixed models of outcome with time and covariates gender and race/ethnicity, as indicated.
[2] Outcome values imputed for consistent length of school day.
[3] Race/Ethnicity a binary variable with values White/Non-Hispanic or Minority (including Black/African-American and Hispanic/Latino students).

<u>Hypothesis 4.b.</u> did not hold true. There was significantly less daily time spent in MVPA in the Virginia 3rd grade sample in the intervention school environment as compared to the independent sample of 3rd graders in the previous Virginia school environment, based on analyses that were unadjusted (p<0.0001) (Table 2.23) and adjusted for gender and race/ethnicity (p<0.0001) (Table 2.24). There were no

significant gender or race/ethnicity effects (Table 2.24), and no significant interaction effects.

Table 2.23. Unadjusted Same-Grade Independent Samples Differences in Daily Time in Moderate to Vigorous Physical Activity (MVPA).

Outcome Variable and Group	N Previous School	Previous School Mean (SD)	N New School	New School Mean (SD)	Mean Difference (SD)	*p*-Value
Daily Time in MVPA						
Independent 3rd Grade Groups	32	25.02 (9.56)	21	11.24 (4.91)	-13.78 (8.06)	<0.0001
Female	10	23.28 (9.36)	11	10.40 (5.09)	-12.88 (7.43)	0.0008
Male	22	25.82 (9.76)	10	12.17 (4.80)	-13.65 (8.57)	0.0002
White, Non-Hispanic	13	21.63 (7.49)	10	10.43 (5.45)	-11.20 (6.69)	0.0007
Minority[1]	16	27.70 (9.98)	4	10.75 (2.11)	-16.95 (9.15)	0.0039

[1] Minority group included Black/African-American and Hispanic/Latino students.

Table 2.24. Adjusted Same-Grade Independent Samples Differences in Moderate to Vigorous Physical Activity (MVPA).

Outcome Variable and Groups		Model Controlling for Gender		Model Controlling for Gender and Race/Ethnicity[2]	
		Parameter Est.[1]	*p*-Value	Parameter Est.[1]	*p*-Value
Daily Time in MVPA					
Independent 3rd Grade Groups	New vs. Old School	-13.32	<0.0001	-13.05	<0.0001
	Female vs. Male	-2.21	0.3456	-1.55	0.5607
	White vs. Minority[2]			-4.00	0.1365

[1] Estimates and *p*-values from linear models of outcome with group and gender; and group, gender and race/ethnicity; as indicated.
[2] Race/ethnicity a binary variable with values White/Non-Hispanic or Minority (including Black/African-American and Hispanic/Latino students).

Survey (Hypotheses 5)

Sample Demographics

At baseline in the previous Virginia school environment, 101 3rd grade students completed surveys with items from three PA psychosocial scales. At follow-up in the new activity promoting school environment, 99 students completed surveys, including some 5th graders who had not completed the survey at baseline. Sample demographics are shown in Table 2.25. The sample was weighted toward males, and self-reported race/ethnicity indicated an approximately 1:3 ratio of White to Minority participating students. There was some loss to follow-up of original participants, primarily due to moves to other locales and schools, as indicated by the final prospective sample sizes in Table 2.26.

Table 2.25. Virginia School Survey Sample Demographics.

Data Collection Groups and Timing	N	Age Years (% N)	Gender		Race/Ethnicity				
			Female	Male	White, Non-Hispanic	Black, African-American	Hispanic/ Latino	Other, Mixed Race	Not Reported
Pre-Occupancy Spring 2012 – 3rd Grade (2nd Semester)									
Total 3rd Grade (VA)	101	8 (32%) 9 (57%) 10 (11%)	37 (36.6%)	64 (63.4%)	34 (33.7%)	35 (34.6%)	3 (3.0%)	26 (25.7%)	3 (3.0%)
Post-Occupancy Fall 2013 – 5th Grade (1st Semester)									
Total 5th Grade (VA)[1]	99	9 (3%) 10 (78%) 11 (19%)	36 (36.4%)	63 (63.6%)	34 (34.4%)	33 (33.3%)	3 (3.0%)	26 (26.3%)	3 (3.0%)

[1] Longitudinal sample was a subset of both the pre-occupancy/baseline and post-occupancy samples, as there was loss to follow-up, and also new students included in the survey at post-occupancy.

In the longitudinal survey sample, students' perceived negative reinforcement for PA decreased, based on analyses that were unadjusted (p=0.0202) (Table 2.26) and adjusted for gender and race/ethnicity (p=0.0121) (Table 2.27). Negative reinforcement was higher overall for Whites vs. Minorities (p=0.0414). PA positive reinforcement moved in the negative direction, but the change was non-significant based upon unadjusted (p=0.1563) (Table 2.26) and adjusted (p=0.1131) (Table 2.27). Positive reinforcement was marginally higher for Whites vs. Minorities (p=0.0821) (Table 2.27). PA self-efficacy moved somewhat in the positive direction, but the change was non-significant based on unadjusted (p=0.1392) (Table 2.26) and adjusted (p=0.1719) (Table 2.27) analyses. There were no significant gender or interaction effects.

Table 2.26. Unadjusted Longitudinal (Within-Subject) Change in PA Psychosocial Scale Measures[1].

Outcome Variable	N	Baseline Mean (SD)	Follow-Up Mean (SD)	Mean Difference (SD)	*p*-Value
Negative Reinforcement for PA	71	1.55 (1.80)	0.93 (1.55)	-0.62 (2.26)	0.0202
Positive Reinforcement for PA	82	8.77 (2.10)	8.27 (2.30)	-0.50 (2.88)	0.1563
PA Self-Efficacy	93	11.30 (2.77)	11.92 (2.75)	0.62 (3.44)	0.1392

[1] Measures from Child and Adolescent Trial for Cardiovascular Health (CATCH) and Health Behavior Questionnaire (HBQ) [219,220].

Table 2.27. Adjusted Longitudinal (Within-Subject) Change in PA Psychosocial Measures[1].

Intervention Group Outcome Variable		Model Adjusting for Gender		Model Adjusting for Gender and Race/Ethnicity[3]	
		Parameter Est[2]	*p*-Value	Parameter Est[2]	*p*-Value
Negative Reinforcement for PA	Time	-0.66	0.0088	-0.65	0.0121
	Female vs. Male[2]	-0.14	0.6216	-0.04	0.8851
	White vs. Minority[3]			0.58	0.0414
Positive Reinforcement for PA	Time	-0.51	0.0991	-0.49	0.1131
	Female vs. Male[2]	-0.00	0.9994	0.12	0.7540
	White vs. Minority[3]			0.65	0.0821
PA Self-Efficacy	Time	0.54	0.1335	0.50	0.1719
	Female vs. Male[2]	-0.48	0.2954	-0.50	0.2889
	White vs. Minority[3]			-0.15	0.7520

[1] From Child and Adolescent Trial for Cardiovascular Health (CATCH) and Health Behavior Questionnaire (HBQ) [219,220].
[2] Estimates and *p*-values from generalized linear mixed models with intervention/time and gender; and intervention/time, gender and race/ethnicity; as indicated.
[3] Race/Ethnicity was a binary variable with values White/Non-Hispanic or Minority (including Black/African American and Hispanic/Latino students).

Summary of Results by Hypotheses

Table 2.28 summarizes directions of outcome changes or differences, and significance levels for the longitudinal intervention and comparison groups, and the same-grade independent cross-sectional groups, for each hypothesis.

Table 2.28. Direction and Significance of Outcome Changes or Differences in Intervention vs. Comparison Groups.

Hypotheses and Outcome Measures	Longitudinal Intervention Group (Virginia)			Longitudinal Comparison Group (New York State)			Independent Cross-Sectional Groups (Virginia)		
	Direction of Change			Direction of Change			Direction of Difference		
	Hypothe-sized	Actual	*p*-Value[1]	Hypothe-sized	Actual	*p*-Value[1]	Hypothe-sized	Actual	*p*-Value[2]
Hypothesis 1. New school environment has a positive impact on total accumulation of sedentary time and sedentary behavior patterns.									
	1.a. Longitudinal changes.						1.b. Cross-sectional differences.		
Daily Time in Sedentary Behavior	-	-	0.1541	+	+	<0.0001	-	-	<0.0001
	1.c. Longitudinal changes.						1.d. Cross-sectional differences.		
Average Length of a Sedentary Bout	-	-	<0.0001	+	+	<0.0001	-	-	<0.0001
Average Length of a Break from Sedentary Behavior	-	-	<0.0001	+	+	0.0210	-	-	0.0221
Average Daily Number of Breaks from Sedentary Behavior	+	+	<0.0001	-	-	0.0015	+	+	<0.0001
Hypothesis 2. New school environment has a positive impact on time spent in LPA.									
	2.a. Longitudinal changes.						2.b. Cross-sectional differences.		
Daily Time in LPA	+	+	0.1377	-	-	0.0001	+	+	0.0001
Hypothesis 3. New school environment has a positive impact on PA overall.									
	3.a. Longitudinal changes.						3.b. Cross-sectional differences.		
Steps per Minute	+	-	0.0261	-	-	0.0275	+	-	0.6405
Hypothesis 4. New school environment has a positive impact on time spent in MVPA.									
	4.a. Longitudinal changes.						4.b. Cross-sectional differences.		
Daily Time in MVPA	+	-	<0.0001	-	-	0.2124	+	-	<0.0001
Hypothesis 5. New school environment has a positive impact on PA psychosocial measures.									
	5.a. Longitudinal changes.								
PA Negative Reinforcement	-	-	0.0121						
PA Positive Reinforcement	+	-	0.1131						
PA Self-Efficacy	+	+	0.1719						

[1] From longitudinal linear mixed models adjusting for gender and race/ethnicity.
[2] From linear models adjusting for gender and race/ethnicity.
[3] From longitudinal generalized linear mixed models adjusting for gender and race/ethnicity.

DISCUSSION AND CONCLUSIONS

This natural experiment of a holistic PA-oriented school environmental change used both longitudinal and cross-sectional comparison groups to document environmental intervention effects on students' sedentary behavior accumulation and physical activity. Results confirmed prior knowledge that, on average, children spend a majority of the school day sedentary, and that school-time MVPA falls far short of the national recommendation that children engage in activities within this intensity category at least 60 minutes per day. However, there were significant improvements in sedentary time and accumulation in the intervention group, and indications of improvements in light activity, while daily time in MVPA decreased. It appears that some design strategies had more positive impact than others within the context of this school.

Although current evidence for the health consequences of sedentary behaviors in children is not in unanimous agreement [198,206,207], studies have shown that sedentary behaviors were associated with cardio-metabolic risk and obesity [200-204]. Some researchers have recommended that MVPA be used as the primary outcome measure to assess activity-related health behaviors in children [198,208], but typically there have been negative correlations between MVPA and sedentary behaviors. This was the case in the longitudinal non-intervention sample, with overall daily time in sedentary behavior as well as lengths of sedentary bouts increasing substantially while time in MVPA moved in the negative direction over the period of the study. These trends were not surprising given substantial prior research showing that children's physical activity tends to decrease with maturation.

However, in the longitudinal intervention sample, there was a downward trend in overall daily sedentary time and evidence of shorter sedentary bouts and more breaks from sedentary, along with a significant decrease in daily MVPA time. In addition, the 3rd graders in the new school exhibited far less time in sedentary behavior, along with less time in MVPA and more time light PA compared to their same-grade counterparts in the previous school facility. These results suggest that sedentary behaviors cannot be assumed to be negatively correlated with MVPA, at least during the school day, and that sedentary metrics should be examined given their potential associations with important health indicators. In both longitudinal and cross-sectional intervention samples, there appeared to be far more frequent movement between sedentary and active behaviors, with shorter sedentary bouts and more frequent and shorter breaks from sedentary behavior. These findings may primarily be consequences of classroom design, with possibly more movement during classroom lessons due to dynamic furnishings, ample space to move and adjust the furnishings, and the potential to stand while working. In addition, drinking fountains within the classrooms may have reduced time and supervision barriers to student’s ability to get up and walk across the room to have a drink of water.

A drop in time in MVPA was consistent and significant in the longitudinal intervention group, and in the same-grade cross-sectional comparison group in the new school facility. There were no substantial changes in school PA policies between the old and new environments, and it is possible that the large size of the new facility had some negative impact on MVPA. Anecdotally, both teachers and students often remarked on the sheer size of the facility, and some teachers complained about the long walking distances to reach daily destinations. Although cross-sectional studies have documented positive associations between larger school environments and PA [109,128], the Virginia school results suggest caution in drawing conclusions that larger schools are “better” for MVPA. In this case, it is possible that longer distances from classrooms in the new school to frequent destinations such as the dining commons, music, and art areas could have had positive impact on school time spent walking, which at a non-hurried pace would likely fall into the category of light PA. Indeed, the longitudinal intervention group showed some increase in time spent in light PA, and the cross-sectional intervention group spent substantially more time (~50 minutes) per day in light PA as compared to their same-grade pre-intervention counterparts. On the other hand, daily time in light PA decreased substantially (~37 minutes) in the non-intervention longitudinal comparison group.

For higher intensity levels of PA, however, it has been well established that children are more physically active outdoors vs. indoors [98-100], and therefore school design may well consider targeting quick access to the outdoors to promote running and other activities in the realm of MVPA that are generally not encouraged or allowed in classrooms and hallways within school facilities. The Kindergarten classrooms at the new Virginia school each had direct access via a door in the classroom (Figure 1.9) to an outdoor play area for younger children (with permanent age-appropriate equipment planned but not yet completed at the time of the study). Anecdotally, we observed many of these children becoming highly active (running, jumping, etc.) almost immediately upon access to the outdoors, and easily improvising active games and activities with loose equipment such as jump ropes, balls, and plastic scoops that were provided. Trailers housing 3rd graders at the previous Virginia school facility offered a short outdoor walk (~260 feet) to the playground/recess area. In the new facility, the walk from the 3rd grade classrooms centrally located on the 2nd floor to the playground outdoors at the sound end of the facility was primarily inside and 1.7 times further (~440 feet). Given this distance, along with a school policy of no running in the building and ‘speeding tickets’ for doing so, the differences in distances in the two environments (and concomitant lengths of time to reach areas where running and other forms of higher intensity activities were allowed) could have had an impact on both LPA and MVPA outcomes. For example, assuming a walking rate of 2-3 miles per hour, the additional walking distance to the playground/recess area in the new facility could account for about 1½ to 2 minutes of time per recess period without opportunity for MVPA. The scheduling of site improvements could have also had some relevance to MVPA measures. Occupancy of the building occurred before landscaping and construction of outdoor play areas were completed. At the time of the post-occupancy data collection, two playground structures had been moved over from the previous facilities, but three additional installations occurred by the end of the following spring.

Based upon longitudinal survey results, changes in PA-related psychosocial outcomes were far less significant than accelerometer-measured changes in active and sedentary behaviors. There was a decrease in negative PA social support, but at the same time also a marginal decrease in positive PA social support. There was a marginal increase in PA self-efficacy. It would appear, based upon these results, that substantial changes in sedentary and physical activity behaviors did not occur purely via psychosocial mediation pathways, and that the environmental intervention likely had direct effects, some intentional and some unintentional.

The study had several limitations. As with many accelerometry studies in the literature, sample sizes were small, but in this case did provide adequate statistical power to detect highly significant sample group changes and differences in outcomes. The small sample size could have limited detection of gender and race/ethnicity effects, however. The longitudinal data were collected in one intervention school group, and in two New York State comparison schools with similar facilities and rural populations to the original school in Buckingham County, Virginia. The cross-sectional accelerometry and longitudinal survey data were collected only in Virginia. Therefore, results may not necessarily generalize to more heterogeneous and non-rural populations and locales. Racial/ethnic diversity was somewhat lower in the longitudinal comparison group as compared to the intervention group, but statistical models adjusted for this variable. Any cross-study comparisons should take into account this study's methodological choices, including measurement of school time only, and 60 second accelerometry epoch lengths. A strength of this study is that longitudinal findings were supported by same-grade independent cross-sectional results, less likely to include maturation effects, in the same school environments. As the intervention was a holistic school environmental change, it was not possible to distinguish and quantitatively analyze individual effects of particular design strategies or environmental variables. In addition, the 14-month post-occupancy data collection occurred at only one point in time, so the study cannot account for or predict trajectories of change beyond then.

The findings are relevant in that they document significant changes in students' sedentary behavior patterns and PA after a move to a new school environment designed explicitly to promote PA during school time. It appears that the active classroom design strategies had positive impact on school-time sedentary and light activity patterns, encouraging more frequent migration across the cut point threshold between the two behavior categories. The school size and long walking distances to destinations allowing or encouraging higher intensity levels of activity could have had some negative impact on MVPA accumulation. Results point to a need for thoughtful and nuanced translation of prior studies' school environment and PA associational evidence, as well as consideration of within-school travel distances along with categories of PA condoned by policy and social norms in various school locations for different age groups. Future hypothesis-driven studies of school environments and PA outcomes may well focus on both sedentary and PA accumulation, incorporating objective relationships in building and site programs (e.g., distances, adjacencies, and sight lines between functional areas), in association with measures of activity social norms and policies in the building and site program areas. Future work might also begin to group or isolate specific school environmental variables, with the eventual goal of determining their potential impact on key population health outcomes.

CHAPTER 3

Agent Based Model Simulation
of School Environment Dynamic Furniture Impact
on Population Obesity and Overweight Prevalence

ABSTRACT

In empirical studies, it has been difficult to account for confounding factors in analyses of built environment impacts on human behavior and health outcomes, and acknowledgement as to the usefulness of systems science approaches for scenario testing to address public health issues and potential intervention scenarios has grown. Meanwhile, studies have shown positive energy expenditure results due to dynamic furniture. Detached furniture is a discrete aspect of the school environment that may be changed relatively easily at any time during a school facility's lifetime. This exploratory study aimed to determine, via computational experiments in simulated populations of male and female elementary school agents, whether use of dynamic furniture in the school environment had an impact on the distal outcome of a school population's obesity and overweight prevalence over time. Incorporating parameters and formulas from literature, an agent based model was used to generate 240 simulated populations of female and male children with 3 physical activity (PA) profiles and their weight status prevalences over a period of 5 years in 2 scenarios (school environments with and without dynamic furniture). Based upon the prevalence trends from the experiments, there was no apparent impact of dynamic furniture use among boys, regardless of activity profile category. There was also no apparent impact of dynamic furniture use among girls with high or medium PA profiles. However, there was some evidence of differing trends among girls with a low PA profile, starting at about year 2, with slightly lower overweight/obesity prevalence by the 5 year point in the intervention vs. control scenario. Although the intervention produced only marginal movement of the weight status prevalence trend line in one population group, use of dynamic furniture in schools may be worthwhile component of PA-oriented interventions, especially given its other established benefits.

BACKGROUND

In empirical studies, it has been notoriously difficult to account for potentially confounding factors in analyses of built environment impacts on human behavior and health outcomes [81,167]. The research best practices of randomization and blinding are generally unattainable in studies of environment and human behaviors. Citizens in a free society make choices as to where they live, work, and recreate, and they communicate about these choices with others. Most environmental interventions are plainly visible to anyone. And, the relatively young body of literature pertaining to environments and behavioral outcomes has not included many long-term longitudinal studies that could begin to inform knowledge about causal pathways toward desirable change in distal population-level outcomes. Meanwhile, acknowledgement as to the usefulness of systems science approaches for scenario testing to address real-world problems [221], including public health issues and questions about potential interventions [222] has grown. This exploratory study used a systems science approach and a computational environment to isolate a single school environmental variable and test for its impact on a distal child population health outcome.

Agent based modeling (ABM) is a complex, rule-based modeling method from systems science, in which each individual agent or 'actor' in the system is represented in computer code. Agents may be placed in the context of a dynamic system's environment and rules, and their actions produce output from the model over a defined period of time. Agent based models are stochastic in nature and thereby can represent random and natural variations found in the real world. Agent based models may incorporate data and findings from diverse sources including surveillance and empirical studies, and may be coded to provide a venue to ask "what if" questions and predict outcomes in various scenarios.

Findings from a number of studies, including the this investigator’s work presented in Chapter 2, have supported the notion that school and classroom furniture can impact patterns and accumulation of sedentary behavior [140,141,143,145]. Other studies have shown in particular that dynamic furniture that allowed and encouraged children’s bodies to continually change positions raised body temperature [148], and also improved learning outcomes [2]. Non-exercise activity thermogenesis (NEAT) has been described as energy expended that is “not from sleeping, eating, or sports-like exercise” and occurs during activities such as fidgeting, typing, sitting, talking, and standing [41]. Research has shown that increases in NEAT have impacted overall energy balance and provided protection against fat gain and obesity [37,40-42].

Detached furniture is a discrete aspect of the school environment that is specified in school design and construction documentation, and that may be changed relatively easily at any time during a school facility’s lifetime. Dynamic and mobile furnishings include chairs that roll, tip, rock, swivel, and accommodate forward- or backward-facing sitting positions, and height-adjustable desks and seating.

The specific aim of this study was to determine, via experiments in simulated populations of male and female elementary school student agents, whether use of dynamic furniture in the school environment could have an impact on the distal outcome of a school population’s obesity and overweight prevalence over time.

METHODS

Agent Based Model

The investigator built upon an agent based model (ABM) framework [223] to enable generation of intervention and control student/agent populations. Agents were defined as elementary school-aged children with the following attributes: age, gender, weight, height, BMI, weight status category, caloric intake, and energy expenditure. The four possible weight status categories were obese, overweight, healthy weight, and underweight. The model was coded to calculate agents' raw BMI scores on a daily basis over time based upon caloric intake and expenditure, to convert scores to BMI percentiles based on the Centers for Disease Control and Prevention (CDC) growth charts for age, and to assign each agent a weight status category based on the BMI percentile [224-226]. The model output obese, overweight, normal, and underweight population prevalences over time for males and females separately. The key model simulation steps are shown in Figure 3.1.

The dynamic furniture intervention in the school environment was represented in the model by a modification of the energy expenditure portion of the energy balance equation. This defined intervention had no impact on agents' caloric intake levels, which was coded to vary randomly as a percentage of the minimum needed to support body weight. In order to distinguish between intervention and control scenarios, the model incorporated accelerometer activity count measures from a lab-based furniture study [65] with students from the Virginia school that was the focus of the study in Chapter 2. This

Figure 3.1. Agent Based Model Simulation Steps.

```
Increase day counter
IF   (day counter <= 1825)    THEN
     Set day's caloric intake for each student
     Set day's energy expenditure (EE) for each student
     IF      (intervention = YES)    THEN
             EE includes energy expended during time on dynamic furniture
     ELSE  (intervention = NO)
             EE includes energy expended during time on conventional static furniture
     Update student's height
     Update student's weight
     Update student's BMI
     Update student's weight status category
     IF    (day counter mod 365) = 0   THEN
           Increase student's age by 1 year
ELSE
Stop simulation
```

study found that there were significant within-subject differences (*p*=0.005) in activity counts on dynamic vs. conventional furniture, with mean counts per minute of 40.82 and 9.81 respectively. Several studies have developed formulas to convert accelerometer-measured activity counts to energy expenditure, and a comparative study of this work [227] determined that a particular regression-derived formula [228] was most accurate in predicting energy expenditure from accelerometer measures performed during light intensity physical activity. Therefore, the agent based model used this formula to convert activity counts while using furniture to energy expenditure values.

Based upon investigator observations of the school routine and calendar, the model assumed that time spent on school furniture (either traditional or dynamic) averaged 10% of overall time in and out of school (including summer vacation away from school), or 6 minutes per hour on average. Energy expenditure in both intervention and control scenarios included calculations that used a random function from energy expenditure distributions based on children's physical activity profiles [229], along with a calculation of daily energy expended during the proportion of time using school furniture, dynamic or conventional. Inputs and outputs of the model are shown in Table 3.1, and model equations and their literature sources are shown in Table 3.2.

Table 3.1. Agent Based Model Inputs and Outputs.

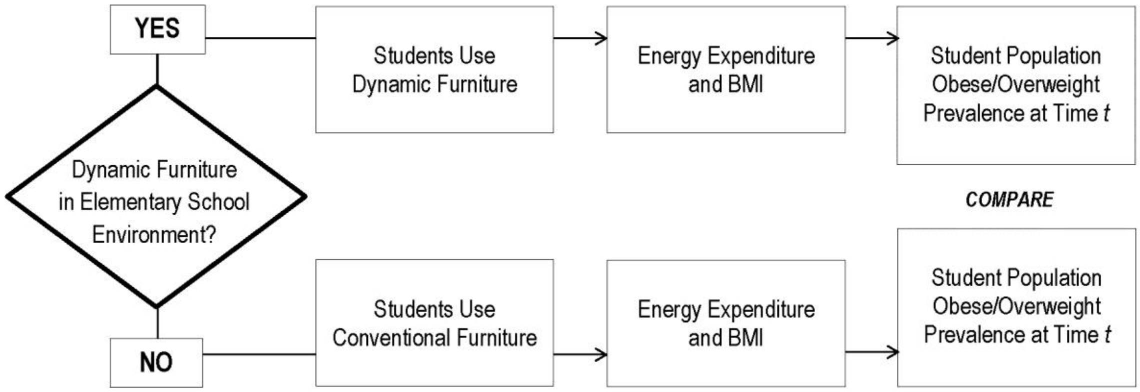
Model Inputs	Value	Source	Model Outputs	
$\boldsymbol{H_1}$	height on day 1 = random selection of height in cm from normal distribution based on average per age where $N(\mu,\sigma)$ = $N(115.66,5)$ for males and $N(115.01,5)$ for females	CDC 2010	$\boldsymbol{H_t}$	$\boldsymbol{Weight\ Status\ Category_t}$ Obese, Overweight, Normal Weight, Underweight, calculated from H_t and W_t based on age and gender
$\boldsymbol{W_1}$	weight on day 1 = random selection of weight in kg from normal distribution based on average per age where $N(\mu,\sigma)$ = $N(21,5)$ for males and $N(20,5)$ for females	CDC 2010	$\boldsymbol{W_t}$	

Table 3.2. Agent Based Model Parameters and Equations.

Parameter	Formula	Units	Components	Sources
AEE	$= 0.0183 + 0.00001 * AC$	Activity energy expenditure in Kcal per kg per minute	AC = accelerometer-measured activity counts per minute	Puyau et al. 2002 Trost et al. 2006
$K_{out-child}$	$= \alpha + 1.71\beta W + EW + 0.1K_{in}$	child energy expenditure in Kcal per day	α and β = constants by gender: α_{female} = 829 β_{female} = 8.7 α_{male} = 879 β_{male} = 11.6 W = weight in kg K_{in} = energy intake in Kcal per day E = physical activity energy expenditure in Kcal per day 1.71 = constant multiplier accounting for children's greater base metabolic rate as compared to adults	Cutler et al. 2003 Schofield et al. 1985
E	$= 0.9(U_{low}(0.5, 3.5)) + 144(0.0183 + 0.00001 * AC)$ $= 0.9(U_{med}(1.5, 4.5)) + 144(0.0183 + 0.00001AC)$ $= 0.9\left(U_{high}(2.5, 5.5)\right) + 144(0.0183 + 0.00001AC)$	physical activity energy expenditure in Kcal per kg per day	U = random selection from uniform distributions of low, medium, and high physical activity energy expenditure ranges 0.9 represents 90% of day not spent on furniture 144 = minutes per day on school furniture (10% of total day) AC = accelerometer-measured activity counts per minute = 40.82 for dynamic furniture or 9.81 for traditional static furniture	Harrell et al. 2005 Puyau et al. 2002 Trost et al. 2006 Garcia et al. 2014
BMI_t	$= \frac{W_t}{H_t^2}$	body mass index on day t	t = day counter	
$BMI\ Percentile_t$	Conversion to percentiles based on age	percentile on day t		CDC Growth Charts
$BMI\ Category_t$	Conversion to weight status category based on percentile	category on day t	Obese >= .95 Overweight >=.85 and <.95 Normal weight >=.05 and <.85	

The model flowchart in Figure 3.2 illustrates the intervention and control scenarios. The model was coded to generate populations of 1,000 student agents, and to output population weight status prevalences over a 5 year period (*t*=1,825 days).

Figure 3.2. Agent Based Model Flow Chart.

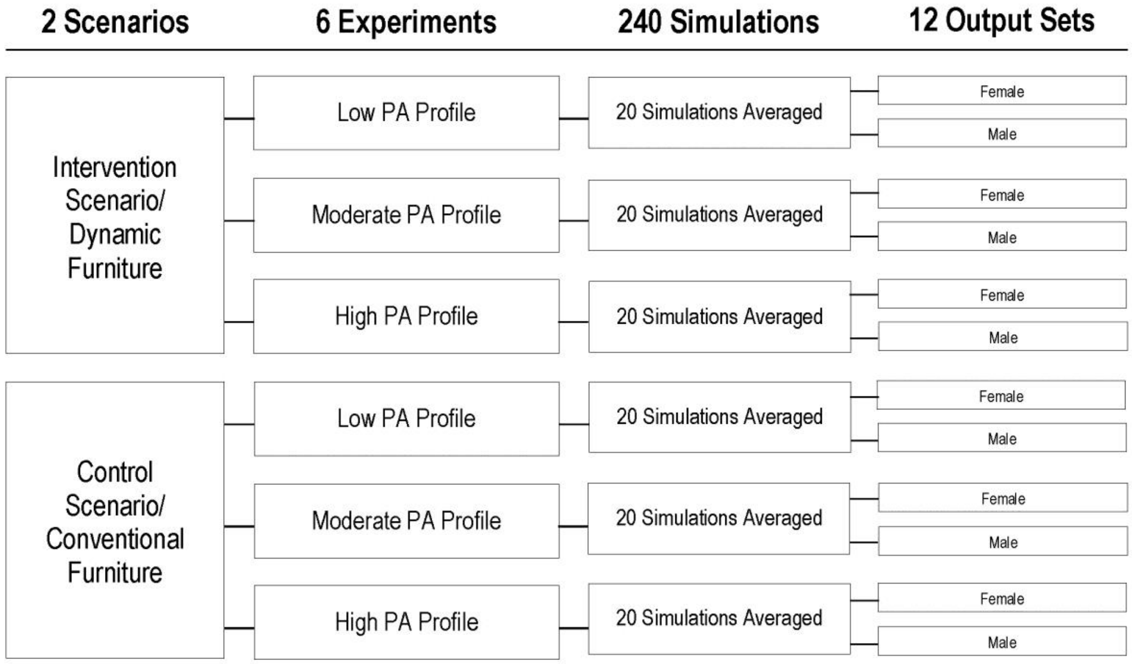


NetLogo software and programming language (Northwestern University, Evanston, IL) were used for model coding and for subsequent simulation experiments.

Designed Experiments

The investigator defined six experimental scenarios based on three (low, medium, and high) categories of youth physical activity profiles [229], with two school environments (intervention with dynamic furniture in the school, vs. control scenario with conventional rigid furniture). For each experiment, 20 populations of 1,000 student agents were generated and population weight status trends simulated. Each simulation generated weight status category population prevalence outcomes for females and males at daily intervals over a period of 5 years. The daily prevalence values from 20 simulations were then averaged for each gender group. There were then two final sets of output for each experimental scenario, one for males, and one for females (Figure 3.3).

Figure 3.3. Diagram of Designed Experiments.



Averaged output values were transformed to ensure equal weight status prevalences on day 1, set to 28.8% for boys and 29.7% for girls based upon a recent study [230], for trend comparison purposes. Trends of combined overweight and obesity prevalence were then graphed and compared based upon physical activity profile and environmental scenario. The data were not intended to represent actual overweight and obesity trends that are occurring in a given population, but rather to offer an opportunity to compare trends over time from a consistent starting point in two very specific environmental scenarios.

RESULTS

For both males and females, higher PA profiles produced a marked reduction over time on overweight and obesity prevalence vs. lower profiles (Figures 3.4-3.5).

Figure 3.4. Male Overweight/Obese Prevalence Over Time by PA Profile.

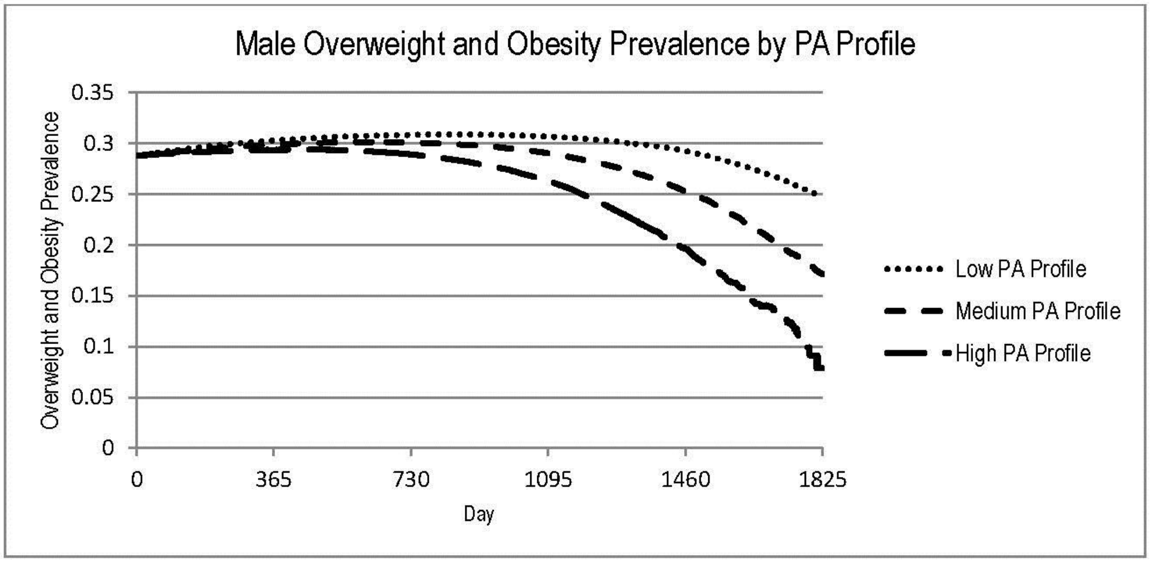
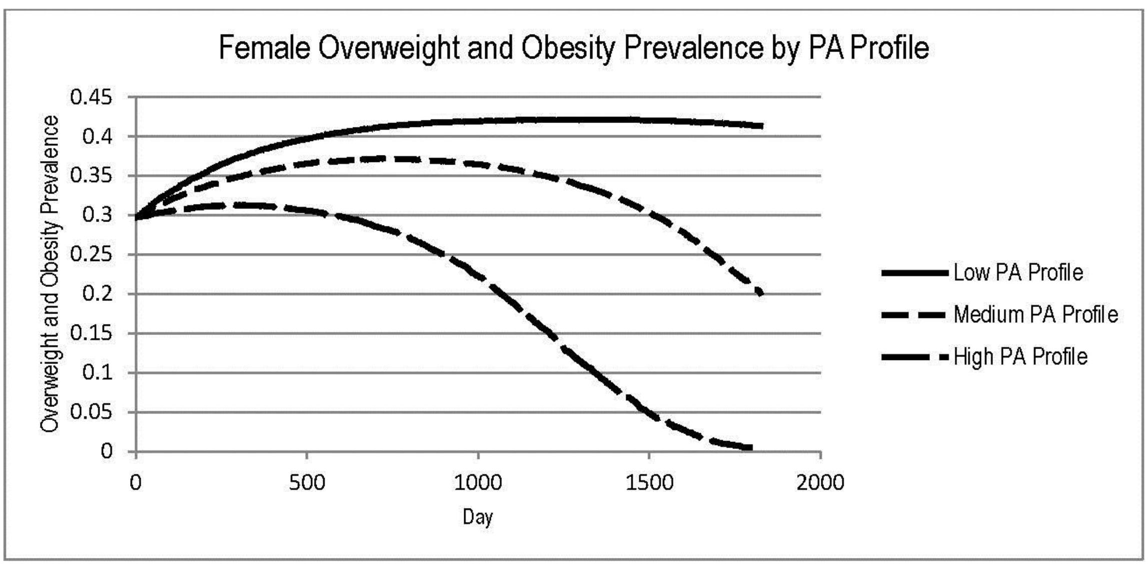


Figure 3.5. Female Overweight/Obese Prevalence over Time by PA Profile.



Among males, regardless of PA profile, there were no apparent impacts of school dynamic furniture use on obesity and overweight prevalence trends (Figures 3.6-3.8).

Figure 3.6. High Activity Profile Male Overweight/Obese Prevalence in Intervention and Control Scenarios.

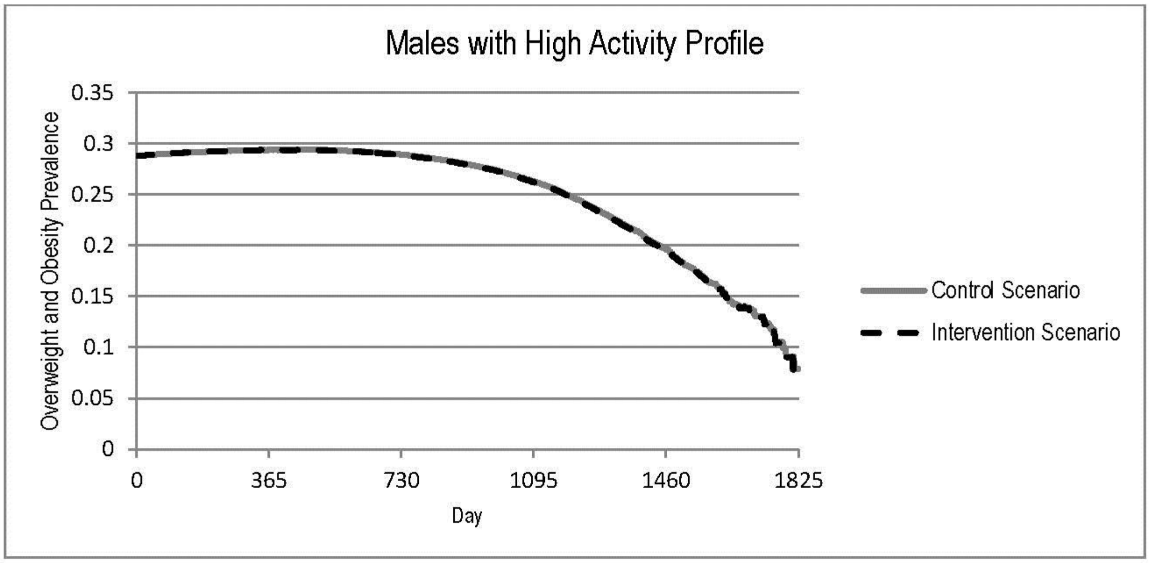


Figure 3.7. Medium Activity Profile Male Overweight/Obese Prevalence in Intervention and Control Scenarios.

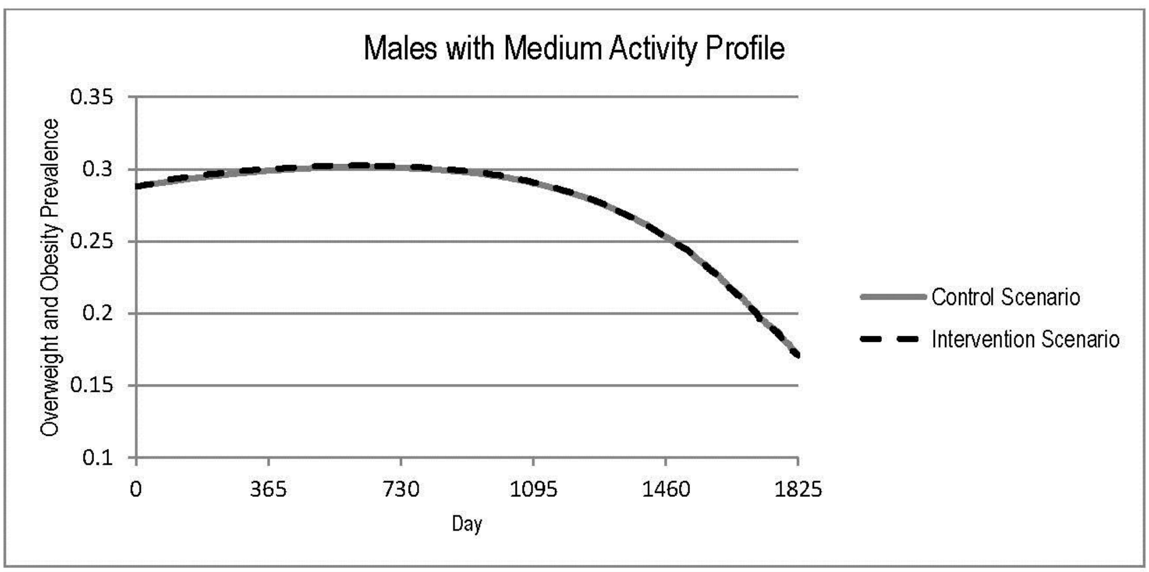
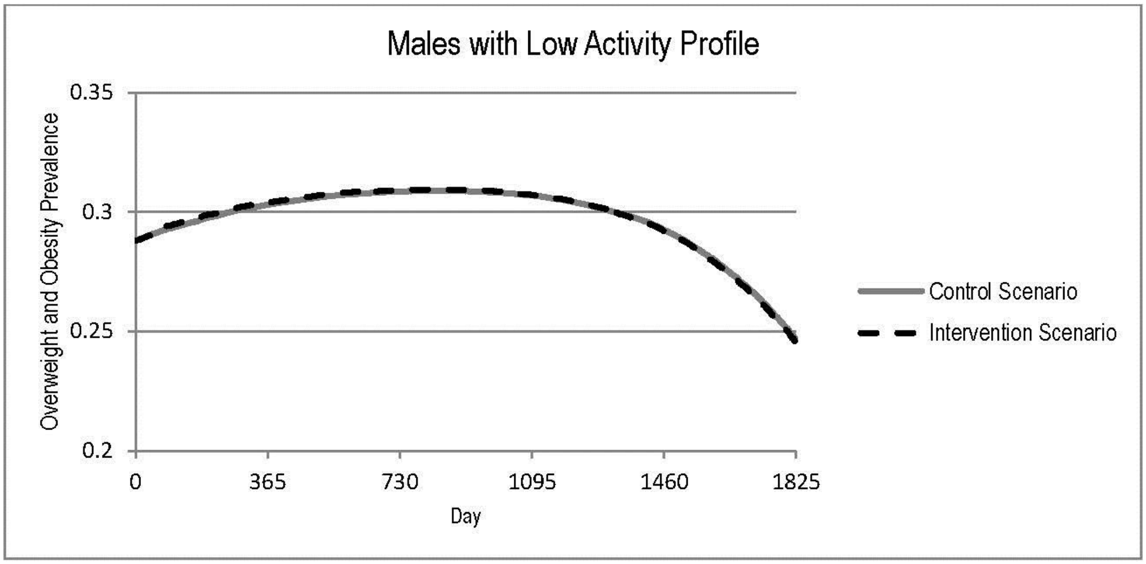


Figure 3.8. Low Activity Profile Male Overweight/Obese Prevalence in Intervention and Control Scenarios.



Among females with high and medium PA profiles, there were also no apparent impacts of school dynamic furniture use on obesity and overweight prevalence trends (Figures 3.9-3.10).

Figure 3.9. High Activity Profile Female Overweight/Obese Prevalence in Intervention and Control Scenarios.

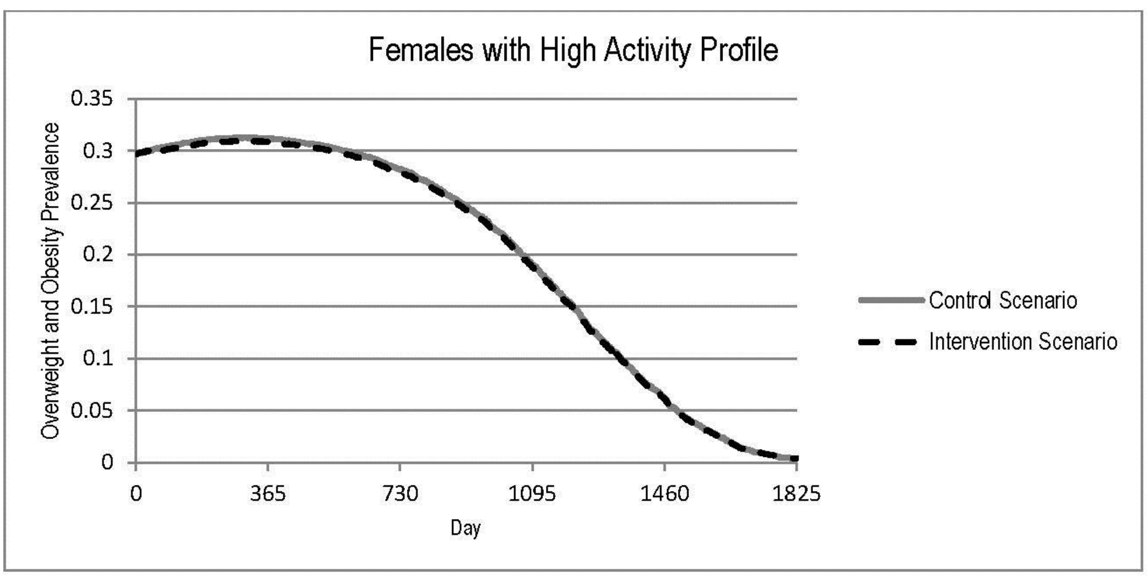
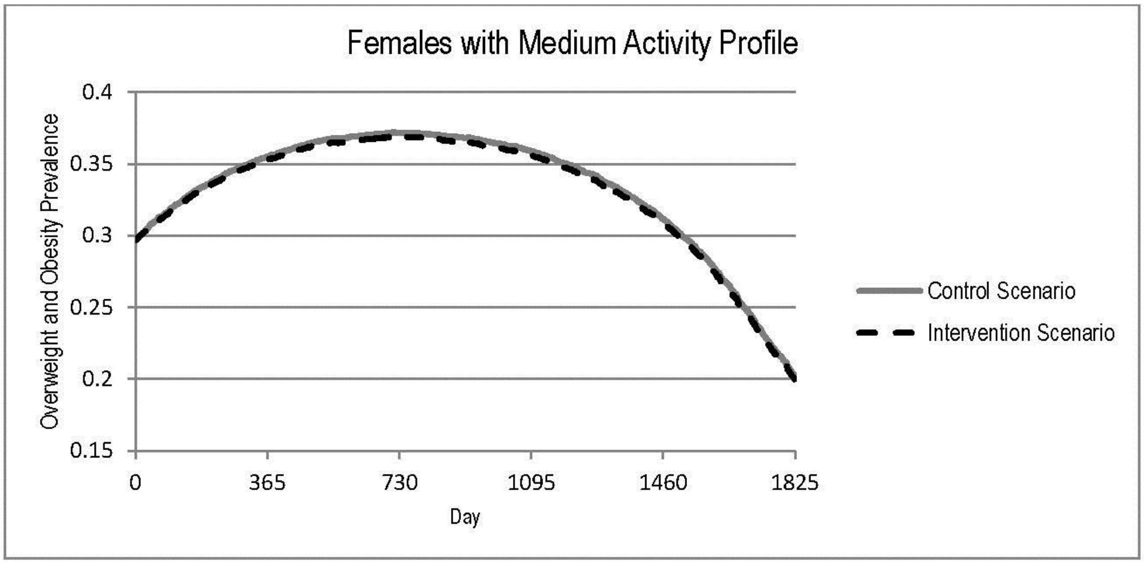
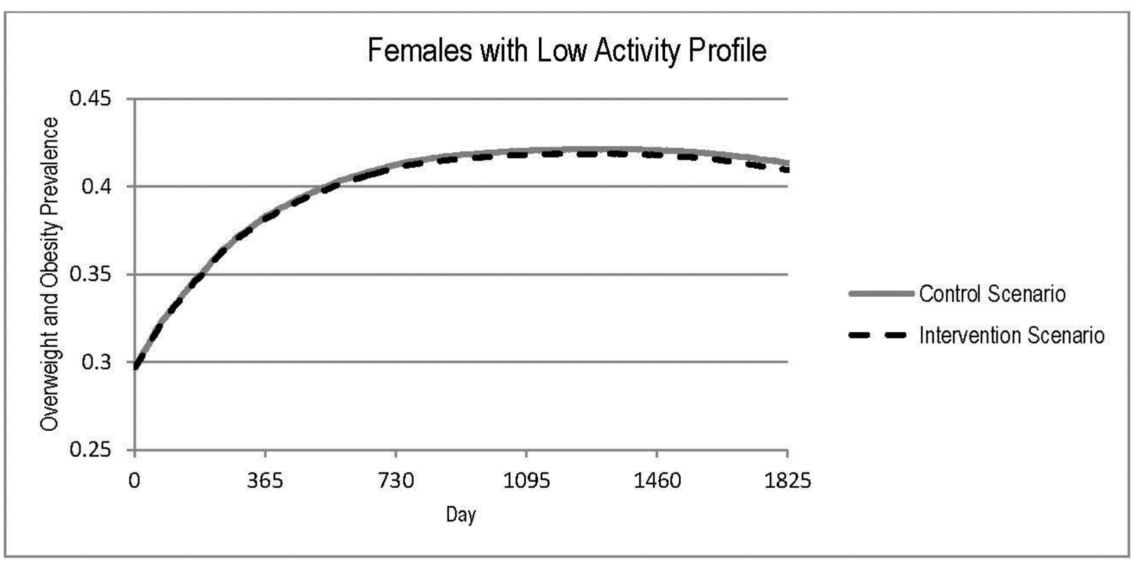


Figure 3.10. Medium Activity Profile Female Overweight/Obese Prevalence in Intervention and Control Scenarios.



Among females with a low PA profile, however, the overweight/obese prevalence trend lines began to separate at approximately year 2, with slight prevalence reduction in the invention scenario vs. the control scenario (Figure 3.11). At year 5, obese/overweight prevalence was ½ percentage point lower in the intervention vs. control scenario.

Figure 3.11. Low Activity Profile Female Overweight/Obese Prevalence in Intervention and Control Scenarios.



DISCUSSION AND CONCLUSIONS

This research posed one specific question about the potential population weight status prevalence impact of dynamic furniture use over a 5-year period during childhood, holding other environmental variables constant. Such an investigation was of interest methodologically to overcome the inherent time and resource obstacles of longer-term natural experiments, as well as the challenges of randomizing samples and isolating environmental intervention variables in experiments. Based upon the prevalence trends from the designed experiments, there was no apparent impact of dynamic furniture use among boys, regardless of their activity profile category. There was also no apparent impact of dynamic furniture use among girls with high or medium PA profiles. These results were not particularly surprising, as the original question was intentionally somewhat far-fetched (in conceivable distance and scale between the intervention and the outcome), and clearly not possible to answer in a empirical study that could realistically be funded. However, interestingly, there was some evidence of differing trends among girls with a low PA profile, starting at about year 2, and with ½% lower overweight/obesity prevalence by the 5 year point in the intervention vs. control scenario. Although the intervention produced marginal movement of the weight status prevalence trend line in one population group, it is clear that dynamic furniture is not a sole solution to the obesity epidemic. However, use of dynamic furniture in schools may be worthwhile component of PA-oriented interventions, especially given its other known benefits, such as improved attention and learning [2].

The most obvious limitation of this research was that the experiments were simulated and did not occur in the real world with human subjects. However, the aim of this research was not to mimic actual population trends, but rather to test the impact of one very specific environmental intervention on a school population, and the model drew upon established empirically-derived parameters and formulas from the literature. That said, knowledge continues to grow as to the complexities and nuances of accurately modeling energy balance and growth in children. For example, in recent research that was published after the genesis of this simulation research, proportions of fat mass vs. lean mass ratios (i.e., not just overall weight and BMI) played key roles in estimations of metabolic function and energy balance [231]. These recent conceptions may well displace older, simpler linear models of energy balance, and such work will no doubt contribute to the sophistication of further simulation model development and approaches for scenario testing in the future.

CHAPTER 4

The Potential of Designing Environments to Promote Health: Theoretical Grounding and Strategies for the Future

BACKGROUND

The prior chapters of this dissertation focused on the design of K-12 school environments to promote children's healthy behavior, measured as several physical activity-related outcomes. The evidence- and best practice-informed *Physical Activity Design Guidelines for School Architecture* presented in Chapter 1 will serve as a practical, spatially-organized, easily-accessible (via the open access journal, *PLoS ONE*) resource for school designers and decision-makers. These *Design Guidelines* acknowledge the school built environment as a determinant of children's health, and begin to bridge a translational gap between research and school design practice. They also provide a starting point for definition of further school environment research opportunities. The strategies may contribute to the advancement of industry and education standards, and are expected to evolve with future development of the evidence base. The longitudinal study presented in Chapter 2 confirmed that health promoting environmental design of one Virginia school – in particular, the active classroom design strategies employed – had a significant positive impact on children's school-time sedentary behavior accumulation patterns and light physical activity (LPA). At the same time, other aspects of the school environment, possibly including the large overall facility size and long interior distances from place to place, may have inadvertently contributed to a reduction over time in moderate to vigorous physical activity (MVPA). This documentation of both intentional and unintentional strong longitudinal effects of an activity-promoting school design adds substantively to the current body of knowledge, and also has important design practice implications. It demonstrates the need for processes to test and evaluate interventions continually, and to reformulate design strategies as appropriate over time toward desired outcomes. The research in Chapter 3 used a computational modeling method to overcome the limits of variable control and expense of a large-scale prospective study, and asked a question about the potential impact of a single school design decision – dynamic vs. conventional furnishings – on the distal outcome of school population obesity and overweight prevalence, finding that there could possibly be some effect in certain groups of children.

The work presented in these chapters represents progress in furthering the development, implementation, and evaluation of purposeful health-promoting design in school environments. It also represents output of a new collaborative model (Figure 1.19) for design and research that hinges upon direct interaction of designers and scientists throughout the design and evaluation process. It was possible due to a visionary client, an architecture firm that embraced the long process of longitudinal research, researchers who were interested in and truly valued the perspectives and knowledge of designers, and all participants' shared desire for a fruitful transdisciplinary collaboration. Unfortunately, due to many barriers, from funding to professional silos, identities and cultures, such collaboration is not the norm in the design industry nor in academic research institutions and public health practice. In this case, the core team, whose individuals had respect for each other and were stubbornly determined to make the collaboration succeed, worked through the inevitable difficulties of communication and negotiation of expectations and timelines, as discussed elsewhere [62]. In addition, each individual faced head-on the challenges and discomforts of engaging in the knowledge and work domains of fields outside of his or her own expertise.

Successful collaborations of environmental designers and research scientists are needed to forge progress toward understanding and fully leveraging the built environment for human outcomes such as improved population health. As groundwork for development of strategies toward such collaborative work, this paper discusses the theoretical foundations for understanding the built environment's human impact, and historical and current perspectives as to the purpose of design. It also briefly addresses progress made in the field that has come to be known as evidence-based design, input from public health about design, and the methodological challenges of studying the built environment's impact on human outcomes. I argue that environmental design can and *should* be driven by informed intent to improve human outcomes such as population and individual health and wellbeing, and propose several strategies toward this goal.

THEORETICAL GROUNDING

There exists a substantial body of theoretical work that explores and attempts to explain relationships between human beings and their environments. This work, largely from the social sciences, has supported the notion that spaces (i.e., the environments or settings in which people go about their daily activities) have enormous, though perhaps often unknown or unacknowledged, impact on individuals' life experiences and behaviors. In his 1951 treatise, the social psychologist Kurt Lewin proposed the notion of 'life space' as a complex psychological field in which individuals and groups act and experience life at given times. Lewin explained the basis for his theory with an analogy to multi-dimensional phase space in physics. His conception of a multi-dimensional life space consisted of a person along with "all that affects behavior" [232] (p.58) at any given time. Other psychologists have described experience and behavior as outcomes of a person's cognitive synthesis of intended activities, external environmental information, and internal information including various schemas (e.g., self-, environmental-, and place-schemas). These schemas can be influenced by social-cultural norms and potentially a multitude of other individual and environmental factors [21]. Others have illustrated the degree to which people experience 'place identity,' or a sense of interconnectedness, with their homes, cities, and other formative environmental settings [233,234]. Work in ecological psychology reinforced the idea of a transactional relationship between individuals and their environmental settings [211]. Structuration theory further defined and elaborated concepts of personal agency, i.e., human action, and its structural explanation in social systems [25].

Subsequent work in the 1980's observed that a discourse on the social logic of architectural space was needed to design effectively, but as of yet had not yet emerged among design academics and critics. Architects Hillier and Hanson set out to develop an understanding of the social origins of spatial order [18]. Via discussion of a significant body of empirical evidence within the field of anthropology about spaces in many societies, they noted lack of consistency, at least when the evidence was viewed through a lens attempting to define external causes (e.g., topography, climate, technology, etc.) of spatial outcomes. Although some structural anthropologists had studied social processes through analysis of space, these authors found that the effectiveness of the approach was not consistent across varying societies. They then suggested that a fatal problem with this approach was that space was viewed merely as a result, or a by-product, of some other deterministic factors. Thus, a theory of space should view, describe and analyze space without assuming such a one-way relationship. They also asserted that a theory of space must take into account wide variations in types and patterns across social systems. They reviewed existing theories of spatial organization, and found some to be useful to a degree – from territoriality to cognitive theory, to analysis of environment as an 'object', to semiology. They determined that none of these took an approach from the perspective of the central problem of designing architecture. They found the semiological approach [235] to be particularly problematic, as it created what they referred to as "the man-environment paradigm," which seemed to presume that environments were merely physical material with no social content and that societies were completely abstract with no spatial content.

In seeking to determine why different spatial patterns emerge from various societies, they noted that buildings were not merely artifacts, as they provided an important social function in the ordering and arrangement of space. Through an investigation of buildings as spatial patterns, two types of relationships became significant: the relationship among the buildings' occupants, and the relationship between the occupants and those on the outside. They then extended this thinking beyond buildings to settlements. In the work of the sociologist Durkheim [236], they found a "missing component" of a theory of space, specifically, a definition of form as a "cell." They identified two paths of growth from a given spatial cell: one of subdividing, to become a building; and one of aggregating, to become a settlement. A more global-to-local system (vs. the local-to-global progression that the above presumes) would reverse the system logic. In either case, the spatial logic of society, and the social logic of space, had gained clarity. Further, space could actually determine society through facilitation, perpetuation, and contribution to societal norms and roles via our structured awareness of and encounters with others through the episodes of daily life.

The revelatory idea from this work was that redefinition of the 'problem of space' must acknowledge society as having intrinsically spatial qualities, and must acknowledge spaces as having intrinsic social qualities. Only then can one begin to articulate relationships between the two that are useful and relevant to designing. Other theorists have echoed this idea. In particular, Canter's metaphor, 'facets of place', nicely illustrated the notion that 'context' (social meaning) and 'arena' (physical form) are intrinsically linked, inseparable dimensions of a whole [19]. In a significant body of work, Rapoport has also ruminated upon reciprocal spatial relationships in the evolution of people and the formulation and meanings of their spaces [237,238].

Ecological theory is also relevant to discussions of the interrelationships of people and places, and the potential for the environment to cause change. A pivotal thinker in this domain, Bronfenbrenner, differentiated types of settings and systems that influence people's activities and development. He defined the micro-setting or microsystem as "the complex relations between the developing person and environment in an immediate setting containing that person" (e.g., home, school, workplace, etc.); the mesosystem as "compris[ing] the interrelations among major settings containing the developing person at a particular point in his or her life"; and the exosystem as "an extension of the mesosystem embracing other specific social structures, both formal and informal, that do not themselves contain the developing person but impinge upon or encompass the immediate settings in which that person is found, and thereby influence, delimit, or even determine what goes on there" [210] (p.515). He then differentiated a macrosystem from the other forms as "general prototypes, existing in the culture or subculture, that set the pattern for the structures and activities occurring at the concrete level" [210] (p.515) Recommending analysis in "system" terms, Bronfenbrenner proposed that the structures of environment, as well as human and other processes within and between environments, are interdependent [210]. Bandura's social cognitive theory [24] further elucidated specific social constructs, such as self-efficacy and social support, that can potentially be measured in settings.

THE PURPOSE OF DESIGN

Throughout the history of design, and today, perspectives have varied as to the purpose of design in the built world. Most perspectives have acknowledged in some way that design serves both function and meaning, with variations in purpose and degree of function, and in the person or people for whom meaning is created. Many have and do view architecture as the artistic expressions of inspired individuals. Writing in 1990, one theorist attempted to quell the Modernist vs. Postmodernist debates of the time, allowing at least some degree of validity to both points of view:

> The task of the theoretician… is not one of Modernism vs. Postmodernism, but rather one of sorting out the good in both. Some of the best architects of our time have demonstrated the way; they have managed to synthesize the good, they have managed to stay "open-minded," and they have created works that we believe Le Corbusier and Alvar Aalto, if they were still alive, would be receptive to and supportive of [239]. (p.ix)

These words conveyed an apparent underlying belief that the revered, paternal heroes of Modernism would know what is best for us. Indeed, the tenets of Modernism were interlaced with lofty, egalitarian social goals, and many of its iconic figures produced masterful, and even emotionally moving, works of architecture. However, the Modernist approach was not necessarily synchronized with the realities and needs of the actual people who would inhabit its structures [240]. The theorist quoted above went on to explore both the intangible and tangible "channels to architectural creativity," including the use of metaphor and paradox, the "primordial," poetry and literature, the "exotic," history and precedent study, geometry, materials, nature, associations with art, architectural biography, and so on. While such a list of suggested approaches could conceivably be useful to explore the possibilities of the architect's creative and artistic expression through form, it would not be particularly helpful to designing with the outcomes of others in mind. In fact, strikingly, there was hardly a mention in the entire tome of the people for whom one might be designing.

A year later, another architectural theorist, Jon Lang, argued that the architecture discipline, as defined by academics and the cognoscenti, had become primarily a high-art form, with a preponderance of emphasis on formalism. Meanwhile, most professionals in architectural practice were left in the rather impossible (and arguably devaluing) position of attempting to aspire to such individualistic artistic goals while serving clients and their organizational objectives. Lang proposed a higher purpose than either of these often conflicting approaches could or would reach:

> The two streams of design thought – design as art and design as environmental design – can and should be brought together within what might tentatively be called a neomodernist normative design theory. It might also be called a behavior deterministic theory because it assumes that designing for human behavior, in its multiplicity of complexities, is the purpose of design [241]. (p.92)

He also asserted that the interior design profession was paying more attention than architecture to "the actual behaviors a building is to house, and to the symbolic function of architecture" [241] (p.89).

Lang suggested that Maslow's model [242] (perhaps over-used but still useful) was pertinent in considering desired functions of environments in relationship to a hierarchy of human needs, adapted here in Figure 4.1 [243]. While a building as sculptural expression of one architect's inclinations might be seen as meaningful by some people (those operating at a level of cognitive/aesthetic need), such work would seem to ignore the needs of the vast majority of people in the world, as well as the corresponding design possibilities.

Figure 4.1. Design Concerns by Hierarchy of Human Need (adapted from Lang, 1991).

Human Need	**Design Concerns/Sociophysical Mechanisms**
Cognitive/aesthetic	Access to developmental opportunities; formal aesthetics; art for art's sake
Self-actualization	Choice; control; access to developmental opportunities
Esteem	Access to services; control; personalization; symbolic aesthetics
Belonging	Access to services and communal settings; symbolic aesthetics
Safety	Access to services; privacy; territorial control; orientation in society, time, and space
Survival	Shelter; access to services

In recent years, there has been some shift in the architecture profession's focus on producing art to a focus on environmental sustainability. This attention to sustainability has spurred developments in building systems, energy efficiency, and materials [243], some of which could have positive secondary impacts on people, such as thermal comfort and access to cleaner, higher quality indoor air. Since the formal designs of structures are integral to these types of systems optimizations, some architects have seen these developments as important opportunities to maintain or re-claim professional territory lost in recent decades to such groups as developers, builders, and engineers. There is policy support for "green building," as the U.S. Green Building Council initiated and maintains the Leadership in Energy & Environmental Design (LEED) rating systems that focus on incorporating systems and materials to improve building outcomes such as efficiency of energy and water use. While it is only tool, the evolving foci of LEED represent increasing interest in health among proponents and practitioners of sustainable building. Historically, based on a review of its language that searched for words such as "health", "comfort", and "wellbeing," LEED has exhibited some inherent, albeit secondary, interest in positively impacting the health of building occupants [244]. As noted in Chapter 1, further LEED developments, such as the Active Design Index [50], are focusing to a greater degree on human health outcomes.

With regard to the building-focused sustainable design trend, architectural theorist Rumiko Handa has advised caution to her profession:

> Professionals are all enthused about the recent technological developments and the opportunities they afford. Like a weather vane that responds decisively to a strong wind, they have veered their attention to materials and techniques of sustainable design. The cloud of self-doubt seems finally lifted, which has been with the profession ever since Modernism failed to fulfill its promise of a better, richer, and fuller life for everyone. Postmodern concession to banality and consumerism and Deconstructivist deferral of meaningful environment had left little to praise architecture for, other than as a spectacle merely on the basis of its novelty and visual effect. With a clear sense of purpose to fulfill

> environmental consciousness, the profession seems finally to have revived its *raison d'etre*. Behind this enthusiasm, however, is a danger associated with anything that comes with positivistic clarity... Architecture should… contribute to our understanding of the world and the self, although its attainment is difficult to measure [245]. (p.1)

In this theorist's view, architecture at its best has a most human impact that is meaningful, and architects have "a moral responsibility to demonstrate the potential of architecture's physical and spatial attributes to contribute to the cultural and spiritual dimensions of human life" [246] (p.60). Handa's position is compelling in its human focus and in its assertion that architecture has the power to change people, for the better. This art of architecture is one that is far less self-serving and self-glorifying than that of those for whom other people are merely an afterthought, if a thought at all, in the process of designing.

DESIGNING FOR HUMAN OUTCOMES

It has been well stated that "[i]f something (e.g., a process, an outcome) cannot be measured, it cannot be improved" [247]. In order for built environmental design to achieve intended human outcomes over time, we must have or develop measures of those outcomes and other the environment (even if this task is difficult), and we must assess, document, and share results of the relationships of design actions to those outcomes. This process would produce a living and evolving body of evidence to inform ongoing work.

The concept of evidence in research grew out of the positivist scientific perspective prevalent through the 20th century, with its assumption that there was a distinct reality or truth that could be studied and objectively known [248]. Today, the perspective in many fields of research may be most aptly defined as postpositivist, with an assumption of a reality that may be nuanced and interconnected with the researcher but still can be known, and with a goal of objectivity among the researchers who create bodies of knowledge [249]. Evidence is used to inform actions and decisions in many fields toward desirable outcomes, and we refer to these intentional actions and decisions as “evidence-based.” Evidence can be defined very broadly as indication or proof. Although the concept of proof may vary to some degree depending upon one’s (or one’s field’s) ontological perspective, there has been general agreement across fields including social research, medicine and nursing, education, psychology, and public health, that the threshold for evidence in research should be much stronger than indication [250-253]. A well-accepted hierarchy of evidence quality has placed randomized controlled trials (RCTs) and systematic reviews of RCTs at the top (often referred to as the “gold standard”), followed by observational studies and systematic reviews of these studies, then followed by – in the case of medicine – clinical observations [252]. Generally, the lowest level of the evidence hierarchy (if included at all in the particular field) has included quasi-experimental designs, surveys, and qualitative research [254].

Evidence-based medicine is now a standard approach to medical treatment, initially defined and named in the early 1990’s. A 1996 article by Sackett and colleagues defined evidence-based medicine as “the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients… [and] integrat[ion] [of] clinical expertise with the best available external clinical evidence from systematic research” [255] (p.71). Prior to this time, it was generally assumed that a physician, faced with a given patient, would somehow, via the ‘art of medicine,’ combine all relevant data, knowledge, and experience to determine the best course of action [256]. However, research began to show that physician practice varied widely and that many inappropriate patient procedures were performed, leading to a focus on the results of significant population-based, randomized controlled trials (RCTs) to inform medical decision-making toward improved and more consistent patient outcomes [256].

Designing for outcomes is the foundational purpose in the field of evidence-based design. The concept was built upon the tenets of evidence-based medicine, as designers adopted focus on patient and other outcomes of interest to their healthcare organization clients over the past two decades. A leader in this field, architect Kurt Hamilton, with clear reference to his medical forebears, defined evidence-based design as “a process for the conscientious, explicit, and judicious use of current best evidence from research and practice in making critical decisions, together with an informed client, about the design of each individual and unique project” [257] (p.9). The Center for Health Design, a nonprofit collaborative formed in 1993 that focuses on healthcare design, defined evidence-based design similarly as “the deliberate attempt to base building decisions on the best available research evidence with the goal of improving outcomes and of continuing to monitor the success or failure for subsequent decision-making” [258] (p.1). Key general outcomes targeted in evidence-based healthcare design have included staff wellbeing and productivity, patient healing and stress reduction, and safety (e.g., reductions of patient falls, medical errors, etc.). Evidence-based design has been developed as a field primarily by healthcare designers and nurses, with a range of backgrounds that may or may not have included training in scientific research. The field has tended to focus since its inception almost exclusively on aspects of the micro-settings of healthcare facility environments, although some evidence-oriented work has also been conducted by design researchers in school and workplace environments.

Meanwhile, and for the most part separately, researchers in the field of public health, with increasing focus on socio-ecological models and “systems” of health, have become increasingly interested in the potential for neighborhood and community environments to have impacts on the health of various populations [259-262]. As noted in the previous Chapters, major societal problems such as the childhood obesity epidemic have spurred public health and policy focus on particular environments, such as schools, as possible settings to promote changes in health behaviors and outcomes [4]. The preliminary bodies of evidence in these areas have been produced almost exclusively by people with scientific research training, without substantial input from design professionals and practitioners.

Seemingly as a result, significant findings of associations between environmental characteristics and behavior or health outcomes have not translated well to inform decisions that must be made in designing spaces and places. For example, multiple public health studies have associated school environmental characteristics with more or higher levels of physical activity, such as a "looping cycle path," a new grass hill [107], a handball goal area [95], larger number of permanent play facilities [89], painting of playground markings [82], and fewer shaded grass surfaces [108]. Such work to date may be useful to some degree in providing input as to what types of features might be included at a school facility to help promote physical activity. However, such work also conveys a superficial understanding of, and a sort of surface orientation to, environmental design. It is not surprising, then, that the proposed strategies in the "Building Massing and Programming" domain of the *Physical Activity Design Guidelines for School Architecture* from Chapter 1 had no evidentiary support. To date, outcomes-oriented research has for the most part neglected the potentially far more consequential possibilities and impacts of what I will call "socio-spatial decision-making." Such a task calls to mind consideration of theoretical descriptions of space, such as Hillier and Hanson's subdividing or multiplying "cells." Although they may not often be overtly thought of as socio-spatial decisions, design professionals in practice make these decisions every day, for example, in massing, ordering, determining adjacencies, and programming the functions of spaces. They make these potentially highly impactful decisions based upon training and experience (and based upon their own hypotheses, although they do not generally use that term), but for the most part not based upon evidentiary support for particular desired outcomes. In this way, spatial design is inherently a social act, and thus may be leveraged toward social and behavioral change.

As with studies in the field of evidence-based healthcare design, empirical studies of the built environment in public health have focused primarily on single micro-settings, although some theoretical work is beginning to explore how multiple settings may interact in the pathway toward desirable outcomes [165].

METHODOLOGICAL ISSUES IN BUILT ENVIRONMENT RESEARCH

A seminal early work in the field of evidence-based design was a 1984 study, published in the prestigious journal *Science*, that showed that hospitalized patients with a view of leafy trees through the window had shorter post-operative stays, and took fewer strong analgesics, than those with a window view of a brick wall. The matched case-control study was relatively small (46 patients), and focused on a specific subset of patients with an acute gall bladder condition requiring a straightforward surgical procedure [263]. Yet, its influence has been significant in pointing attention to a potential restorative role of natural views and environments explored in subsequent theory and empirical research [264-266]. Today, although actual empirical evidence has arguably been over-generalized to globally-applied design actions, it is unheard of to encounter a newly designed hospital that lacks “views of nature” and a “healing garden.”

While the medical origins of evidence-based design have led design researchers to aspire to biomedical approaches generating evidence via quantitative, controlled, experimental trials (ideally, RCTs), researchers doing place-based work continually struggle with meeting these standards. True randomization is generally not possible in environmental settings and place-based studies, as people are able, at least to some degree, to choose where to live, to attend school, to obtain medical treatment, and so on. And, environmental interventions are usually plainly visible, precluding the research practice of blinding. Cluster randomized designs are sometimes a viable alternative to the RCT. However, the “setting of any treatment matters,” leading to limitations for meta-analyses across sites, and leading to intentional minimization of ultimately positive spillover effects between groups for the sake of strengthening study designs [81]. Therefore, future methodological exploration is in order in research on the built environment and health.

BRIDGING THE ‘TRANSLATIONAL GAP’ BETWEEN RESEARCH AND DESIGN PRACTICE (AND VICE VERSA)

As discussed, among the design professions, there is a range of points of view as to the purpose of design. Among designers for whom the purpose of design is focused more on self expression than on outcomes for users, research connecting design factors and such outcomes is not likely to be deemed a relevant pursuit. However, most design professionals wish to apply their work to improve outcomes for users. Research is not widely available or accessible in their workplaces, however, and, as noted, the current body of research often does not answer consequential questions designers need to answer in their day-to-day work. Professional designers tend to use case studies and precedents, popular media, as well as client and site information, to inform their work. Even for those who might have time, interest, and access to more formal research literature, professional design training has not generally included coverage of research designs and methods, statistical analysis, or appropriate interpretation and application of evidence from research. The Center for Health Design has created an evidence-based design accreditation and certification (EDAC) credential, which requires an exam that covers basic knowledge of research designs, methods, and issues [267]. The credential has for the most part been pursued by designers of healthcare facilities.

STRATEGIES TOWARD A HEALTH-PROMOTING BUILT WORLD

By merging Lang's proposal for a neomodernist or behavior deterministic design theory with the outcomes-oriented purpose of evidence-based design practice, along with acknowledgement and persistence that design can and should be art, *when users' are at that level of need,* we might begin to formulate a new normative design theory: "Good design" then purposefully addresses and promotes the health and wellbeing of populations via effective and creative socio-spatial decision-making. Environmental design can thus support positive social and behavioral goals, as well as potentially enhance human life at deep and meaningful levels. Lewin's term "life space" [231] has more recently been used, and quite profoundly simplified, as an assessment of mobility and function based on the extents of an area, from within the home to around the town and beyond, regularly traversed by individuals with health issues [268]. Perhaps some re-complication of the term for use in designing environments to promote health would be worthwhile.

A wealth of knowledge and theory support the notion that built environment can have real and positive influence on people, so there is an ethical argument to move beyond mere empirically based understandings of human behavior (the traditional focus in the social sciences) to deliberate interventions using design to address complex real-world problems. Kurt Hamilton, referring to healthcare facility design, has argued that designers have an ethical responsibility to "base their work on the careful interpretation of the best evidence from credible research findings and rigorous analysis from practice" to improve clinical outcomes and safety. He also has called upon healthcare administrators (the clients) to accept this responsibility [269] (p. 129). I would argue that this responsibility should extend to other design practice focus areas, and to clients as well.

Professions have been defined based on realms of expertise, and it would be unrealistic to expect these professional silos of knowledge, and the protective cultures around these knowledge domains, to change quickly. However, it may be worthwhile to consider enhancement of design education with some focus on research methods, basic statistics, and appropriate interpretation and application of evidence. Perhaps we might develop specializations in strategic outcomes-oriented design and translation of evidence to design action, to complement the more tactical and technical, or artistic design skills that have tended to receive focus in design education. Design education might also include more transdisciplinary work and collaboration. Some schools and researchers have already proposed curricula combining public health research and urban planning, to foster healthy communities [270]. It is worthwhile for designers to collaborate with other professionals with relevant knowledge, especially researchers in public health.

It is also worthwhile, and necessary, for public health researchers to collaborate with professional designers. Scientists who conduct built environment research should engage with environmental design professionals in formulation of relevant questions whose answers can be well interpreted and applied to places that are being created and altered every day. Socio-spatial decision-making must be addressed in research questions about human impacts. Building upon recommendations from work of the environmental psychologist Frances Kuo [271], scientists would do well in their research to:

- Select independent variables that matter to stakeholders (decision and policy makers, funders, *and* users of environments)
- Select dependent variables that environmental design professionals can purposefully apply in socio-spatial and other design decision-making
- Select questions, in collaboration with environmental design professionals, that stakeholders (decision and policy makers *and* users of environments) find compelling
- Select research designs and methodologies that can reasonably inform causal interpretations
- Present findings in forms and venues that are accessible to environmental design professionals

As for research designs and methods, scientists who do place-based research need to consider the frequent incongruence of randomized experimental controlled research design standards with the settings for their questions. The Institute of Medicine's "Locate Evidence, Evaluate Evidence, Assemble Evidence, Inform Decisions" (L.E.A.D.) framework has offered "ways to increase flexibility and broaden perspectives while adhering closely to concepts of what makes evidence credible as well as useful" [254] (p. 4), and these approaches should be considered.

Use of advanced statistical methods creating synthetic controls to achieve randomized control standards when real-world randomization is not possible, as well as propensity scoring methods to adjust for population differences for meta-analytic efforts covering and comparing multiple sites might be explored further [81]. Scientists who do built environment research might also explore the possibilities of rigorous mixed methods to reveal and deal with complexities that may not be apparent or sufficiently understood through purely quantitative work [272]. Complex systems science and modeling may be another approach to exploring the potential of designed environmental interventions on human outcomes [273], prior to implementation in real-world settings and systems, as was illustrated in the limited example in Chapter 3.

CONCLUSION

Both public health research and design practice should be focused on continual improvement, questioning, and application of knowledge via design toward built environments that enhance human experience and improve human lives. In order to make this lofty ideal possible, the translational gap between research and design practice must be addressed, scientists must engage designers and vice versa, and place-based research needs to address head-on the limits of traditional biomedical approaches. A better (health-promoting) built world awaits.

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