UNRAVELLING ENVIRONMENTAL INFLUENCES ON CHILDREN'S PHYSICAL ACTIVITY

Teun Remmers

Unravelling Environmental Influences on Children's Physical Activity

The research presented in this thesis was conducted at

Maastricht University

at the Department of Epidemiology, in the context of

CAPHRI
Care and Public Health Research Institute

and was funded by

NWO
Netherlands Organisation
for Scientific Research

project number 328-98-005.

ISBN: 987-94-6299-785-1

Layout: Martin van Dijk

Production: Ridderprint

Cover design: Teun Remmers

Unravelling Environmental Influences on Children's Physical Activity

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de Universiteit Maastricht,
op gezag van de Rector Magnificus, Prof. dr. Rianne M. Letschert,
volgens het besluit van het College van Decanen,
in het openbaar te verdedigen op

woensdag 6 december 2017 om 16:00 uur.

door

Teun Remmers
geboren op 1 maart 1988 te Rosmalen

Promotor

Prof. dr. S.P.J. Kremers

Copromotores

Dr. C.T.M.C.N. Thijs

Dr. S.I. de Vries (The Hague University of Applied Sciences)

Dr. ir. D. Ettema (Utrecht University)

Beoordelingscommissie

Prof. dr. N.K. de Vries (Chair)

Prof. dr. ir. M.W.J. Jansen

Prof. dr. R. Ruiter

Dr. J. Schipperijn (University of Southern Denmark)

Prof. dr. S.B. Vos (Eindhoven University of Technology)

TABLE OF CONTENTS

CHAPTER 1

General Introduction

The Importance of Physical Activity in Youth

The importance of regular Physical Activity (PA) for children's health and well-being is well understood, both worldwide and in the Netherlands. For example, the World Health Organization's Global Recommendations for Physical Activity and Health state that children should participate in at least 60-minutes per day of moderate-to-vigorous PA (MVPA) (1, 2). In the Netherlands, this resulted in comparable PA guidelines of 60-minutes of MVPA per day (3). These guidelines additionally advocate that the relationship between PA and health is continuous; any increment of PA irrespective of the type, intensity, frequency or duration is related to additional benefits for children's general health and well-being. Also, activities should be promoted that strengthen muscles and bones, whereas prolonged sedentary time should be avoided (3). These guidelines reflect recognition of the importance of PA (3). According to national and international monitoring studies, many children are insufficiently active (4, 5). Increasing evidence suggests that PA declines considerably as children age, and that this inactivity tracks from childhood into adolescence and adulthood (6, 7).

Several studies have indicated that inactivity is directly linked with various detrimental consequences for health and well-being, such as cardiovascular risk factors and bone health (8, 9). Increasing evidence also suggests that PA in children may enhance academic performance in schools (10), general cognitive functioning (11, 12), and social capabilities in children (13). Besides these potential direct influences, PA may also be beneficial for the prevention of overweight and obesity (8, 14), which in turn may lead to the prevention of type 2 diabetes, hypertension and decreased self-esteem (15-17). Over the last decades, overweight and obesity have dramatically increased among youth in Western countries (18). In the Netherlands, the prevalence of overweight and obesity increased by two- to three-fold in the last three decades, with prevalence rates around 13.3% and 14.9% for boys and girls in 2009, respectively (19).

Although previous experimental studies have shown promising results of providing exercise programs for overweight children, results from observational studies investigating relationships between PA and body composition are still mixed (8, 14). This may be primarily caused by differences in assessing PA (e.g. parental-reports, self-reports or objective measurements), or differences in study design (i.e. the majority of studies used cross-sectional designs). As the possibility of reversed causation cannot be ruled out in interpreting results from these observational studies (i.e. PA influencing body composition versus body composition influencing PA), longitudinal designs are warranted to further unravel the potential role of PA in the prevention of obesity. Hence, the *first aim* of this thesis was to investigate longitudinal associations between objectively measured PA and body mass index (BMI) development in 4-9-year-old children, and to assess variations in this association by age, gender, and initial weight status.

Determinants of Physical Activity in Youth

Development of effective PA interventions requires knowledge about determinants of PA. Several conceptual frameworks propose that PA is surrounded by individual-level factors and various layers of environmental factors (20). Some frameworks even provide insight into possible pathways by which environmental factors, individual factors or socio-demographical factors might influence PA (21, 22). For example, the Environmental Research framework for weight Gain prevention (EnRG framework) postulates that environmental factors (i.e. in the physical, sociocultural, political or economic domain) are directly related to PA, but also via cognitive mediators such as perceived behavioral control or attitude. In addition, this framework also identifies individual-level cognitive factors (e.g. habit strength, gender, personality traits) that moderate both the direct and indirect pathways between environmental factors and PA (21, 23).

Determinants at the Individual Level

One of the most consistent factors associated with children's PA is gender. In almost all observational and experimental studies, boys are more active than girls (24-26). Also, there is solid evidence that PA declines with age in the transition from childhood to adolescence (10-15-year-olds) (6, 27, 28). Only a few studies have suggested that lower social-economic status or ethnic background may also be related to PA, potentially via less PA-supportive lower social-economic status neighborhoods (29). Inspired by for example the Theory of Planned Behavior (30) and the Social Cognitive Theory (31), there has been considerable interest in socio-cognitive factors that might explain children's PA intention and self-reported PA behavior (32, 33). Social-cognitive theories describe a merely conscious pathway of reasoned action and planning towards behavior, whereas children's PA is considered spontaneous and intermittent (34, 35). Therefore, these social-cognitive theories explain bigger proportions of variance for intention compared to self-reported behavior (32). Alternatively, the Self Determination Theory describes a spectrum of types regarding quality of motivation. This spectrum describes a continuum of four externally fostered motivational types (i.e. external, introjected, identified and integrated regulation) where the source of motivation can be for example a reward of avoidance of negative affect. At the other end of the spectrum, motivation can be intrinsic when it is fostered from the enjoyment of the activity itself, without discernible reinforcement of reward (36). Generally, results from previous studies showed that more autonomous forms of motivation were related to more PA in physical education and leisure time, but strength of these associations were weak (37). Also, children who are intrinsically motivated experience higher levels of PA enjoyment, and may thus be more likely to be active compared to other children (38). However, based on the idea of Physical Literacy (39), motivation, attitude and self-concept may only be part of a larger multidimensional construct that determines a child's capacity to interact with its environment through physical movement (40). A physical literate child has the physical capacities (e.g. fundamental movement skills), the psychological capacities (e.g. perceived competence and enjoyment) and behavioral capacities (e.g. self-regulatory skills) to interact in various PA-contexts (40).

In the current literature, results from studies investigating individual determinants of PA in children and adolescents are still mixed, inconclusive, and primarily based on self-reported outcomes. Studies with more complex conceptual models and objective measurements of PA are therefore warranted to unravel this relationship. Therefore, the *second aim* of this thesis was to investigate individual-level determinants of PA, including both socio-demographical and psychological determinants of objectively measured PA.

Environmental Determinants of PA

Several reviews have been conducted on potential direct relationships between environmental factors and PA in children (41-44). There is some marginal evidence suggesting that residential density, land-use mix and access to PA facilities are potential determinants of PA in the physical environment (41), while social support and parental influences are potential determinants of PA in the sociocultural environment (45-47). However, results from these studies are difficult to compare due to differences in assessing both PA and characteristics of the environment (42). In addition, results from previous studies are still largely based on cross-sectional designs, and focus on either environmental factors or individual-level factors. Future studies that investigate both individual and environmental determinants of PA in longitudinal designs are warranted. In addition, complex conceptual models that investigate moderation between environmental determinants and behavior may be the next step in understanding pathways between exposure to certain environments and daily PA behavior in children (48, 49). Moderation exists when the strength or direction of a relationship differs for a third moderating variable. For example, boys may perceive other environmental attributes as PA-supportive than girls.
Consequently, our *third aim* was to investigate longitudinal associations between the perceived environment and children's outside play, and potential pathways by which the interplay between perceived environmental determinants influences this behavior.

Methodological Advances in Measuring PA and Environmental Determinants

Previously, evidence for environmental determinants of PA was largely based on self-reported or parent-reported data. Although subjective reports can provide valuable insights into clearly defined and understandable PA-contexts (e.g. organized sports participation or outside play), it lacks information about the intensity and the location in which PA is performed. In addition, several studies pointed out significant biases in self-reporting and parent-reporting children's PA (50-52).

Towards Objective Measurement of context-specific PA

Recently the use of objective measurements has become the standard in PA research, which significantly improved researchers' abilities to accurately quantify the frequency, intensity, and duration of PA in children (53, 54). One of the most used devices are accelerometers, which have shown good reliability in assessing children's PA (55, 56). However, accelerometers alone do not provide information about the context in which PA occurs (e.g. school or transport). The context is essential in understanding differences in total daily PA between children, and provides future interventions with valuable information regarding the specific behavioral context to target (e.g. promoting active transport vs. organized sports participation). Based on the internal timestamps (as recorded, in, for example, accelerometers), studies have recently demonstrated time-segmented associations. For example, in children, their school-schedules provide important insights into relative contributions of school hours and after school periods to their total objectively measured PA (28, 57). In addition, based on these accelerometer timestamps, additional subjective data (e.g. dairies) or objective data (e.g. registries of meteorological information) can be aligned with the accelerometer data.

Towards Measurement of Objective Environmental Determinants of PA

Comparing results from studies that investigate environmental determinants of PA is hampered by differences in measurement mode of both PA and the environment (41). Previous studies generally conceptualized the physical environment as either the perceived environment or objective environment. The perceived and objective environment may be conceptually different, as the perceived environment may differ from one person to another, irrespective of their residential neighborhood (58, 59). An important consideration in studies investigating environmental determinants is the conceptual match between the environment and PA (60, 61). This means that environmental determinants are behavior-specific (e.g. cycling paths as determinant of active transport), and that increased specificity of both PA and environmental attributes is necessary to understand how the environment influences PA (60). Due to its accuracy and reliability, some researchers stated that objective measurements of the environment are preferred. For example, Geographical Information Systems (GIS), which hold extensive data about location and characteristics of the environment, may be used for these purposes.

Combining Accelerometers with Global Positioning Systems

Recently, frameworks have been developed for linking objective measures of PA with measurements of location data using Global Positioning Systems (GPS) (62-64). This allows for passively collecting continuous objective data of both PA and geographical location, which subsequently can be combined based on timestamps. Moreover, when these data are presented within GIS, information about the contextual environment in which PA occurs can be inferred from the contemporaneously measured location or travel speed (62, 65-67). In this way, specific objectively measured environmental attributes can be linked to conceptually matched PA activities.

The *fourth aim* of this thesis was to apply these optimized methodologies in investigating the influence of the objective environment on children's PA patterns, and to investigate the development of these patterns in the transition from childhood to adolescence.

Outline of this thesis

The studies presented in this thesis have used data from various cohorts. First, the KOALA study is a birth cohort study that started in the year 2000 with the recruitment of around 2800 healthy pregnant women from the general Dutch population (68). Initial focus of this cohort was on the development of children's asthma and allergies, but subsequently measurements of growth and (un)healthy behaviors such as PA were also performed. Second, the PHASE-kids study is a cohort study that aimed to investigate the development of PA patterns of Dutch children transitioning from primary to secondary school, and relationships with the environment. Furthermore, this thesis also used data from the Be Active Eat Right study, which is a cluster-randomized controlled trail on the effectiveness of an overweight-prevention protocol in 44 Youth Healthcare centers in the Netherlands (69). In addition, data was used from the Active Living study, which is a school-tailored multicomponent intervention study focusing on improving attributes of the physical and social environment in the vicinity of 21 Dutch primary schools (70). Finally, this thesis also used data from the Patterns of Habitual Activity across Seasons (PHASE) study, which used a repeated measures design to examine seasonal changes in children’s activity levels in Melbourne, Australia (71).

The current thesis reports on a series of studies to improve our understanding of individual and environmental determinants of PA in childhood and adolescence (see Table 1). Chapter 2 reports on a study that investigated the longitudinal relationship between PA and the development of Body Mass Index (BMI) in 4-9-year-old children. Chapter 3 focuses on the association between PA enjoyment and PA behavior, and discusses moderating influences of several socio-demographic factors and personality traits. Chapter 4 describes a longitudinal study on children's parent-reported outside play and determinants of the social- and perceived physical environment, whereas Chapter 5 also focuses on moderating factors in the relationship between the social- and physical environment and children's subjectively measured outside play. Chapter 6 presents a study on the influence of daily weather on children's objectively measured PA across the four seasons, and whether this relationship was moderated by day of the week (i.e. weekday versus weekends), socio-demographics, and children's BMI. Chapter 7 and 8 focus on relationships between objectively measured attributes of the physical environment and accelerometer-measured afterschool PA in 8-12-year-old children. Finally, Chapter 9 describes a longitudinal study on context-specific PA patterns of children in the transition from primary to secondary school, and investigates whether PA patterns differ by gender and differences in home-school distances as a result of the change to secondary school.

Table 1: Overview of the studies presented in this thesis

Chapter	*Study Sample*	*Study Design*	*Main Exposure*	*Main Outcome*
First aim: investigating associations between PA and BMI development in children				
2	KOALA	Longitudinal	Objective daily PA	BMI
Second aim: investigating children's individual-level determinants of PA using complex conceptual models				
3	KOALA	Cross-sectional	Self-reported PA enjoyment	Objective daily PA
Third aim: investigating associations between the perceived environment and outside play in children				
4	Be Active Eat Right	Longitudinal	Parent-perceived environment	Parent-reported outside play
5	KOALA	Longitudinal	Parent-perceived environment	Parent-reported outside play
Fourth aim: investigating the influence of the objective environment on children's PA patterns				
6	PHASE Australia	Longitudinal	Objective weather elements	Objective daily PA
7	Active Living	Cross-sectional	Objective built environment	Objective afterschool PA
8	PHASE-kids	Cross-sectional	Objective built environment	Objective afterschool LTPA and AT
9	PHASE-kids	Longitudinal	Transition to secondary school	Objective PA patterns

BMI = Body Mass Index. LTPA = Leisure Time Physical Activity. AT = Active Transport

References

1. Twisk JWR. Physical activity guidelines for children and adolescents. Sports Medicine. 2001;31(8):617-27.
2. Armstrong N, Welsman JR. The physical activity patterns of European youth with reference to methods of assessment. Sports Medicine. 2006;36(12):1067-86.
3. Gezondheidsraad. Beweegrichtlijnen 2017. Den Haag: Gezondheidsraad 2017; publicatienr. 2017/08.
4. Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U. Global physical activity levels: surveillance progress, pitfalls, and prospects. The Lancet. 2012;380(9838):247-57.
5. Hildebrandt V, Chorus A, Stubbe J. Trend report physical activity and health 2008/2009. Leiden: TNO; 2010.
6. Telama R. Tracking of physical activity from childhood to adulthood: a review. Obesity Facts. 2009;3:187-195.
7. Kristensen PL, Møller N, Korsholm L, Wedderkopp N, Andersen LB, Froberg K. Tracking of objectively measured physical activity from childhood to adolescence: the European youth heart study. Scandinavian Journal of Medicine & Science in Sports. 2008;18(2):171-8.
8. Janssen I, LeBlanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. International Journal of Behavioral Nutrition and Physical Activity. 2010;7(40):1-16.
9. Boreham CAG, McKay HA. Physical activity in childhood and bone health. British Journal of Sports Medicine. 2011;45.
10. Singh A, Uijtdewilligen L, Twisk JW, Van Mechelen W, Chinapaw MJ. Physical activity and performance at school: a systematic review of the literature including a methodological quality assessment. Archives of Pediatrics & Adolescent Medicine. 2012;166(1):49-55.
11. Biddle SJ, Asare M. Physical activity and mental health in children and adolescents: a review of reviews. British Journal of Sports Medicine. 2011.
12. Sibley BA, Etnier JL. The relationship between physical activity and cognition in children: a meta-analysis. Pediatric Exercise Science. 2003;15(3):243-56.
13. Burdette HL, Whitaker RC. Resurrecting free play in young children: looking beyond fitness and fatness to attention, affiliation, and affect. Archives of Pediatrics & Adolescent Medicine. 2005;159(1):46-50.
14. Strong WB, Malina RM, Blimkie CJ, Daniels SR, Dishman RK, Gutin B, et al. Evidence based physical activity for school-age youth. The Journal of Pediatrics. 2005;146(6):732-7.
15. Ebbeling CB, Pawlak DB, Ludwig DS. Childhood obesity: public-health crisis, common sense cure. The Lancet. 2002;360(9331):473-82.
16. Dietz WH. Health consequences of obesity in youth: childhood predictors of adult disease. Pediatrics. 1998;101(Supplement 2):518-25.

17. Daniels SR. The consequences of childhood overweight and obesity. The Future of Children. 2006:47-67.
18. Wang Y, Lobstein T. Worldwide trends in childhood overweight and obesity. Pediatric Obesity. 2006;1(1):11-25.
19. Schönbeck Y, Talma H, van Dommelen P, Bakker B, Buitendijk SE, HiraSing RA, et al. Increase in prevalence of overweight in Dutch children and adolescents: a comparison of nationwide growth studies in 1980, 1997 and 2009. PloS One. 2011;6(11).
20. Swinburn B, Egger G, Raza F. Dissecting obesogenic environments: the development and application of a framework for identifying and prioritizing environmental interventions for obesity. Preventive Medicine. 1999;29(6):563-70.
21. Kremers SP, De Bruijn G-J, Visscher TL, Van Mechelen W, De Vries NK, Brug J. Environmental influences on energy balance-related behaviors: a dual-process view. International Journal of Behavioral Nutrition and Physical Activity. 2006;3(1):9.
22. Spence JC, Lee RE. Toward a comprehensive model of physical activity. Psychology of Sport and Exercise. 2003;4(1):7-24.
23. Lakerveld J, Brug J, Bot S, Teixeira PJ, Rutter H, Woodward E, et al. Sustainable prevention of obesity through integrated strategies: The SPOTLIGHT project's conceptual framework and design. BMC Public Health. 2012;12(1):793.
24. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJ, Martin BW. Correlates of physical activity: why are some people physically active and others not? The Lancet. 2012;380(9838):258-71.
25. Sallis JF, Prochaska JJ, Taylor WC. A review of correlates of physical activity of children and adolescents. Medicine & Science in Sports & Exercise. 2000;32(5):963-75.
26. Trost SG, Pate RR, Sallis JF, Freedson PS, Taylor WC, Dowda M, et al. Age and gender differences in objectively measured physical activity in youth. Medicine & Science in Sports & Exercise. 2002;34(2):350-5.
27. Brooke HL, Atkin AJ, Corder K, Ekelund U, van Sluijs EM. Changes in time-segment specific physical activity between ages 10 and 14 years: A longitudinal observational study. Journal of Science and Medicine in Sport. 2014;19(1):29-34.
28. Harding SK, Page AS, Falconer C, Cooper AR. Longitudinal changes in sedentary time and physical activity during adolescence. International Journal of Behavioral Nutrition and Physical Activity. 2015;12(1):44.
29. Gordon-Larsen P, Nelson MC, Page P, Popkin BM. Inequality in the built environment underlies key health disparities in physical activity and obesity. Pediatrics. 2006;117(2):417-24.
30. Ajzen I. The theory of planned behavior. Organizational Behavior and Human Decision Processes. 1991;50.

31. Bandura A. Human agency in social cognitive theory. American psychologist. 1989;44(9):1175.
32. Plotnikoff RC, Costigan SA, Karunamuni N, Lubans DR. Social cognitive theories used to explain physical activity behavior in adolescents: a systematic review and meta-analysis. Preventive medicine. 2013;56(5):245-53.
33. Babic MJ, Morgan PJ, Plotnikoff RC, Lonsdale C, White RL, Lubans DR. Physical Activity and Physical Self-Concept in Youth: Systematic Review and Meta-Analysis. Sports Medicine. 2014;44(11):1589-601.
34. Welk GJ, Corbin CB, Dale D. Measurement issues in the assessment of physical activity in children. Research Quarterly for Exercise and Sport. 2000;71(2):59-73.
35. Baquet G, Stratton G, Van Praagh E, Berthoin S. Improving physical activity assessment in prepubertal children with high-frequency accelerometry monitoring: a methodological issue. Preventive Medicine. 2007;44(2):143-7.
36. Hagger MS, Chatzisarantis NL. Intrinsic motivation and self-determination in exercise and sport. Champaigne, IL: Human Kinetics; 2007.
37. Owen K, Smith J, Lubans DR, Y. JY, Lonsdale C. Self-determined motivation and physical activity in children and adolescents: A systematic review and meta-analysis. Preventive Medicine. 2014;67:270-9.
38. Wenthe PJ, Janz KF, Levy SM. Gender similarities and differences in factors associated with adolescent moderate-vigorous physical activity. Pediatric exercise science. 2009;21(3):291-304.
39. Whitehead M. The concept of physical literacy. European Journal of Physical Education. 2001;6(2):127-38.
40. Giblin S, Collins D, Button C. Physical literacy: importance, assessment and future directions. Sports Medicine. 2014;44(9):1177-84.
41. Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth: a review. American Journal of Preventive Medicine. 2011;41(4);442-455.
42. Ding D, Gebel K. Built environment, physical activity, and obesity: what have we learned from reviewing the literature? Health & Place. 2012;18(1):100-5.
43. Ferreira I, Van Der Horst K, Wendel-Vos W, Kremers S, Van Lenthe FJ, Brug J. Environmental correlates of physical activity in youth–a review and update. Obesity Reviews. 2007;8(2):129-54.
44. Davison K, Lawson C. Do attributes in the physical environment influence children's physical activity? A review of the literature. International Journal of Behavioral Nutrition and Physical Activity. 2006;3(1):19.
45. Hohepa M, Scragg R, Schofield G, Kolt GS, Schaaf D. Social support for youth physical activity: Importance of siblings, parents, friends and school support across a segmented school day. International Journal of Behavioral Nutrition and Physical Activity. 2007;4(1):54.

46. Strauss RS, Rodzilsky D, Burack G, Colin M. Psychosocial correlates of physical activity in healthy children. Archives of Pediatrics & Adolescent Medicine. 2001;155(8):897-902.
47. Trost SG, Loprinzi PD. Parental influences on physical activity behavior in children and adolescents: a brief review. American Journal of Lifestyle Medicine. 2011;5(2):171-81.
48. Gubbels J, Van Kann D, de Vries N, Thijs C, Kremers S. The next step in health behavior research: the need for ecological moderation analyses - an application to diet and physical activity at childcare. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1);52.
49. Ding D, Gebel K. Built environment, physical activity, and obesity: What have we learned from reviewing the literature? Health Place. 2012;18(1);100-5.
50. Prince SA, Adamo KB, Hamel ME, Hardt J, Gorber SC, Tremblay M. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. International Journal of Behavioral Nutrition and Physical Activity. 2008;5(1):56.
51. Sallis JF, Saelens BE. Assessment of physical activity by self-report: status, limitations, and future directions. Research Quarterly for Exercise and Sport. 2000;71(2):1-14.
52. De Vries SI, Hopman-Rock M, Bakker I, Van Mechelen W. Meeting the 60-min physical activity guideline: effect of operationalization. Medicine & Science in Sports & Exercise. 2009;41(1):81-6.
53. Barisic A, Leatherdale ST. Importance of frequency, intensity, time and type (FITT) in physical activity assessment for epidemiological research. Canadian Journal of Public Health. 2011;102(3):174.
54. De Baere S, Lefevre J, De Martelaer K, Philippaerts R, Seghers J. Temporal patterns of physical activity and sedentary behavior in 10–14 year-old children on weekdays. BMC Public Health. 2015;15(1):791.
55. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. Journal of Sports Sciences. 2008;26(14);1557-65.
56. De Vries SI, Van Hirtum HW, Bakker I, Hopman-Rock M, Hirasing RA, Van Mechelen W. Validity and reproducibility of motion sensors in youth: a systematic update. Medicine and science in sports and exercise. 2009;41(4):818-27.
57. Arundell L, Ridgers ND, Veitch J, Salmon J, Hinkley T, Timperio A. 5-year changes in afterschool physical activity and sedentary behavior. American Journal of Preventive Medicine. 2013;44(6);605-11.
58. Heath GW, Brownson RC, Kruger J, Miles R, Powell KE, Ramsey LT. The effectiveness of urban design and land use and transport policies and practices to increase physical activity: a systematic review. Journal of Physical Activity and Health. 2006;3(S1):55-76.
59. Gebel K, Bauman AE, Sugiyama T, Owen N. Mismatch between perceived and objectively assessed neighborhood walkability attributes: prospective

relationships with walking and weight gain. Health & Place. 2011;17(2):519-24.
60. Giles-Corti B, Timperio A, Bull F, Pikora T. Understanding physical activity environmental correlates: increased specificity for ecological models. Exercise and Sport Sciences Reviews. 2005;33(4):175-81.
61. Saelens BE, Handy SL. Built environment correlates of walking: a review. Medicine & Science in Sports & Exercise. 2008;40(S7);550.
62. Jankowska MM, Schipperijn J, Kerr J. A framework for using GPS data in physical activity and sedentary behavior studies. Exercise and Sport Sciences Reviews. 2015;43(1):48.
63. Klinker CD, Schipperijn J, Toftager M, Kerr J, Troelsen J. When cities move children: development of a new methodology to assess context-specific physical activity behaviour among children and adolescents using accelerometers and GPS. Health & Place. 2015;31:90-9.
64. Schipperijn J, Kerr J, Duncan S, Madsen T, Klinker CD, Troelsen J. Dynamic accuracy of GPS receivers for use in health research: a novel method to assess GPS accuracy in real-world Settings. Frontiers in Public Health. 2014;2:21.
65. Chaix B, Meline J, Duncan S, Merrien C, Karusisi N, Perchoux C, et al. GPS tracking in neighborhood and health studies: a step forward for environmental exposure assessment, a step backward for causal inference? Health & Place. 2013;21:46-51.
66. Carlson JA, Jankowska MM, Meseck K, Godbole S, Natarajan L, Raab F, et al. Validity of PALMS GPS scoring of active and passive travel compared with SenseCam. Medicine & Science in Sports & Exercise. 2015;47(3):662-7.
67. Kerr J, Norman G, Godbole S, Raab F, Demchak B, Patrick K. Validating GPS data with the PALMS system to detect different active transportation modes. Medicine & Science in Sports & Exercise. 2012;44:647.
68. Kummeling I, Thijs C, Penders J, Snijders BE, Stelma F, Reimerink J, et al. Etiology of atopy in infancy: the KOALA birth cohort study. Pediatric Allergy and Immunology. 2005;16(8);679-84.
69. Veldhuis L, Struijk MK, Kroeze W, Oenema A, Renders CM, Bulk-Bunschoten AM, et al. Be active, eat right, evaluation of an overweight prevention protocol among 5-year-old children: design of a cluster randomised controlled trial. BMC Public Health. 2009;9(1):177.
70. Van Kann DH, Jansen M, De Vries S, De Vries N, Kremers S. Active Living: development and quasi-experimental evaluation of a school-centered physical activity intervention for primary school children. BMC Public Health. 2015;15(1):1315.
71. Ridgers ND, Salmon J, Timperio A. Too hot to move? Objectively assessed seasonal changes in Australian children's physical activity. International Journal of Behavioral Nutrition and Physical Activity. 2015;12(1):77.

CHAPTER 2

Relationship between physical activity and the development of body mass index in children

This chapter has been published as:

Remmers T, Sleddens EF, Gubbels JS, De Vries SI, Mommers M, Penders J, Kremers SP, Thijs C. Relationship between physical activity and the development of body mass index in children. Medicine & Science in Sports & Exercise. 2013;46(1):177-84.

Abstract

Purpose: Studies estimating the contribution of physical activity (PA) to the development of body mass index (BMI) in critical periods of childhood are warranted. Therefore, we have prospectively investigated this relationship in boys and girls of the KOALA Birth Cohort study, the Netherlands, in the period around adiposity rebound (i.e. 4-9 years old).
Methods: PA was assessed in 470 children (231 boys, 239 girls) using accelerometers at the ages of 5 and 7 years, and height and weight were measured at 5, 7, and 9 years. BMI z-scores were calculated to standardize for age and gender. Leaner and heavier children were classified according to the 25th and 75th percentile of our study sample. To examine longitudinal relationships between PA and BMI z-scores, generalized estimating equation analyses were performed, stratified for gender and baseline weight status (leaner, normal weight, and heavier children).
Results: In heavier children, an increment of 6.5 minutes of moderate to vigorous physical activity (MVPA) was related to a subsequent decrease of 0.03 BMI z-scores both in boys (95% CI = -0.07 to -0.001) and girls (95% CI = -0.05 to -0.002). Light physical activity was also associated with a decrease of BMI in heavier boys but not girls. In normal weight children, MVPA was associated with decrease of BMI in boys but not girls.
Conclusion: In both heavier boys and girls, increments in MVPA between the ages of 4-7 years were associated with beneficial BMI development. Promoting MVPA should remain a major prevention vehicle for improving body composition in 4-9 year-old children.

Introduction

The Netherlands is no exception to the worldwide trend of rising childhood overweight and obesity. In 2-21 year-old Dutch boys, overweight and obesity rose from 9.4% in 1997 to 13.3% in 2009. In girls of the same age, prevalence rose from 11.9% to 14.9% (32).

Childhood overweight and obesity leads to various risk factors, both short term (e.g. decreased cardiovascular fitness, depression, body dissatisfaction, and social isolation) (11) and long term consequences (e.g. decreased insulin sensitivity) (7), resulting in a higher combined metabolic- and cardiovascular risk. In addition, childhood overweight and obesity, and the accompanying consequences, tend to persist into adolescence and adulthood (34), leading to considerably higher healthcare costs for the general population (35). Hence, the improvement of childhood body composition will provide major benefits for the current and future health of these children. Examining key determinants and critical periods for the prevention of an unhealthy body composition is an important topic in pediatric research.

Children may be more vulnerable to the development of overweight at certain stages of childhood (23). After a rapid increase in body fat in the first two years, a second naturally occurring increase in body fat (i.e. the adiposity rebound), is identified as a critical period in the development of subsequent adiposity (9). In normal circumstances, the adiposity rebound initiates at around the age of 5-6 years. An earlier occurrence of this rebound period has been found to be associated with a greater skinfold thickness and body mass index (BMI) at later ages (27, 39). Hence, 5-6 year-old children are an important target group for examining the effect of determinants on the development of body composition (9).

Considering the relatively high incidence of overweight in children in the last two decades, the etiology of the present epidemic is more likely to be caused by energy metabolism-related behaviors than genetic influences (25). Earlier studies that have investigated the relationship between energy expenditure and body composition have generally found that higher energy expenditure is related to less accumulation of body fat in children (14), however more recent evidence for this association is less clear (40). Research concerning more specific measures of energy metabolism-related behaviors, such as physical activity (PA), may therefore provide more meaningful results (14).

PA behavior can be specified according to its duration, frequency, type, and intensity (23). The PA behavior of children is considered less structured than of adults, containing relatively short bouts of intense, spontaneous PA behavior (23, 40). Because this type of PA behavior is difficult to observe, the usage of subjective measurements (e.g. parental reports) are prone to significant measurement errors (30). Objective measurements (e.g. accelerometers) are independent of these biases, and are therefore able to provide more reliable and valid estimates of a child's daily PA behavior (8, 20).

Because reversed causation plays a major role in the interpretation of cross-sectional research concerning the relationship between PA and body composition, longitudinal designs are superior. Only a small number of longitudinal studies investigating primary prevention of weight gain have measured PA objectively, which makes the available evidence insufficient and inconclusive (40). Three studies have previously examined this relationship longitudinally in pre-pubertal children, using objective measurements of PA. First, the study of Moore et al. (22) followed a sample of 103 four year-old children for seven years. They reported that higher levels of PA at baseline were associated with lower BMI scores and lower skinfold thicknesses in later childhood. Second, the study of Jago et al. (17) reported a significant inverse relationship between PA and the development of BMI over three years in 3-4 year-old children. Finally, Metcalf et al. (21) did not find a significant relationship between complying with health-enhancing PA recommendations and development of BMI scores, waist circumferences, and skinfold thicknesses over three years in 5-8 year-old children.

The effect of PA on the development of body composition has a different clinical implication for children with a heavier initial (baseline) body composition, compared to children with a leaner initial body composition. Because possible influences from dietary compensation or the additional accumulation of muscle mass as a result of strenuous PA may influence the association between PA and BMI development, acknowledging a differential effect in these subgroups may provide new insights. As energy intake is considered to cluster considerably with PA, controlling for energy intake would lead to unwanted indirect controlling for PA. Moreover, as a higher level of PA leads to higher energy intake, controlling for energy intake would annul the observed relations. Therefore, we decided to focus solely on the effect of PA, and energy intake was not controlled for in this study. The acknowledgment of potential gender differences is also important in studies concerning PA and the development of body composition in children, because girls are considered to be less active compared to boys (38) and display a considerable decline in activity energy expenditure before puberty compared to boys (15).

The aim of this study was to contribute towards a better understanding of how PA and the development of BMI are related. Compared to other studies, this study is unique in investigating a time span including the adiposity rebound period (i.e. 4-9 years old), its acknowledgment of potential gender differences, the investigation of differences in children with a high initial versus low initial BMI, and the categorization in various intensities of objectively measured PA. We hypothesize that the relationship between PA and BMI decreases in initially heavier boys and girls.

Methods

Study design and population

The longitudinal relationship between PA and BMI (Figure 1) was examined in two subsequent time periods (diagonal arrows in Figure 1), further defined as the "period". In the first period (i.e. first diagonal line in Figure 1), we measured a child's PA level at 4-5 years (T_0), and body height and weight at both 4-5 (T_0) and 6-7 years (T_1). In the second period (i.e. second diagonal line in Figure 1), we measured a child's PA level at 6-7 years (T_1), and body height and weight at both 6-7 (T_1) and 8-9 years (T_2). All parents gave written informed consent. The present study was approved by the Medical Ethics Committee of Maastricht University Medical Center+.

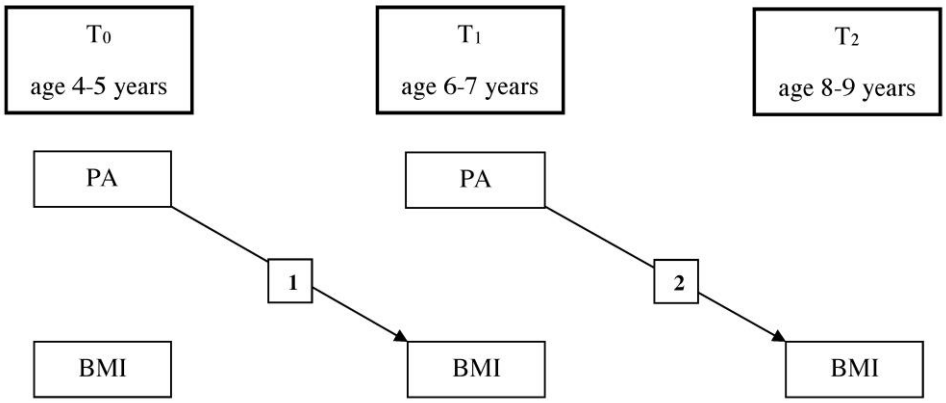


Figure 1: Conceptual model, presenting longitudinal relationships between physical activity (PA) and body composition (BMI). Note: **1**: first period; **2**: second period.

The present study is a prospective study, nested in the KOALA Birth Cohort Study. The study started in 2000 with the recruitment of healthy pregnant women from the general population who participated in an ongoing prospective cohort study on pregnancy-related pelvic girdle pain (conventional recruitment group, *N* = 2343). In addition, healthy pregnant women with an alternative lifestyle were recruited through Steiner schools, organic food shops, and anthroposophic doctors, midwives and magazines (alternative recruitment group, *N* = 491) (16).

The current study was performed in a subsample of the KOALA cohort. Children were eligible for the first assessment period (T_0) if all questionnaires in the child's first two years of age were complete, and if the child resided within 20 kilometers of six selected study locations, an inclusion criterion for a prior study within the KOALA cohort (7). Children were eligible for the second assessment period (T_1) if accelerometer data were available from the first period, and if the mother had participated in blood sampling at 36

(± 1) weeks of pregnancy (6). Figure 2 depicts the number of children participating in each assessment period.

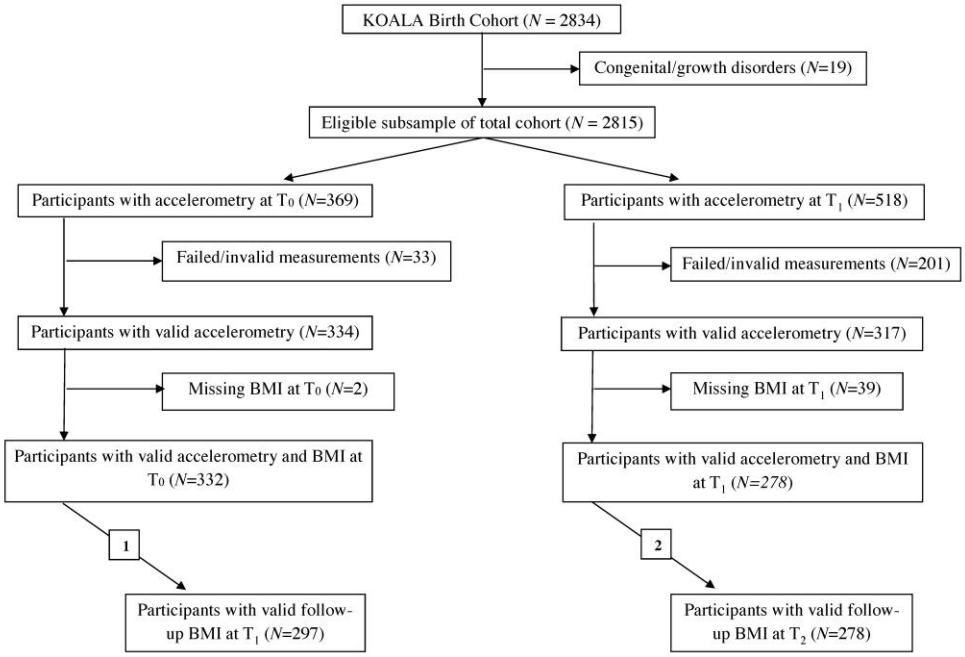


Figure 2: Flowchart

Measurements

Physical activity

PA was measured with the uniaxial ActiGraph 7164 in the first assessment period, and with the ActiGraph 7164 and GT1M accelerometers (ActiGraph, Fort Walton Beach, FL) in the second assessment period. Participants were instructed to wear the accelerometer during waking hours on the right hip for seven days, and to remove the accelerometer during activities in which water was involved, such as swimming. Accelerometers express PA in “counts”, and were initialized to capture the frequency of these counts every 15 seconds (i.e. epochs). Although efforts were made to prevent the occurrence of measurements in non-regular weeks, occasional measurement-days within holidays were excluded from further analyses. In addition, the exact dates at which PA measurement commenced were categorized into four seasons (i.e. spring, summer, autumn, winter) to control for seasonality effects.

Only measurements that contained at least two week days and one weekend day were considered to be valid and were used in the analyses (37). Each day should consist of at least 400 minutes of registration time. Periods of 60 consecutive minutes of no accelerometry counts were considered to be non-wearing time (37). We used the thresholds of Evenson (12) to distinguish between sedentary behavior (0-25 counts per epoch), and PA of light (26-573 counts per epoch), moderate (574-1002 counts per epoch), and vigorous intensity (≥ 1003 counts per epoch). The validation study by Evenson was performed in 5-8 year-old children, which is comparable to our study sample. Time spent in the moderate and vigorous categories were summed into moderate to vigorous PA (MVPA), as internationally recommended (24).

As accelerometers tend to underestimate cycling and cannot measure swimming/water activities, parents were asked to directly report the minutes that their child spent on these activities in a diary. The daily average number of minutes of cycling and swimming were calculated from weekly totals. As these activities were non-normally distributed they were categorized into three categories (cycling: ≤ 10, 11-30, and ≥ 31 minutes per day; swimming: 0, 1-20, and ≥21 minutes per day).

Body mass index

Parental height and weight were assessed in an annual questionnaire at the child's age of 4-5 years old. The child's body height and weight were measured by trained research assistants with a portable stadiometer (Leicester height measure) and digital scale (CAS personal scale, HE-5) and recorded as millimeters and grams (rounded off to 100g), respectively. This was done at T_0 in all children, and at T_1 and T_2 in those children who wore the accelerometer at that time. At other times parents were asked to measure height and weight as part of annual questionnaires. The method of measurement of height and weight at follow-up (i.e. objectively measured or parent reported) was controlled for in multivariate analyses. Children's BMI z-scores were calculated using reference values from the Fourth Dutch Growth Study to standardize for age and gender (13).

In both periods, we combined objectively and parent-reported height and weight measurement methods. In the first period, all height and weight measurements were obtained by research assistants at baseline (i.e. T_0), and 24.6% measurements were obtained by research assistants at follow up (i.e. T_1). In the second period, 49.3% of measurements were obtained by research assistants at baseline (i.e. T_1), and 24.8% of measurements were obtained by research assistants at follow up (i.e. T_2).

Data analyses

Data from both time periods were combined using SPSS 19 for Windows. The distributions of the main continuous variables (BMI z-scores, percentage time spent in different PA intensity categories) were approximately normal, so no transformations were needed. The relationship between PA and the development of BMI z-scores was investigated, controlling for time period, recruitment group, gender, method of height and weight measurement, cycling, swimming, seasonality, maternal BMI and paternal BMI. In the first

time period (arrow 1 in Figure 1), the child's BMI z-score at T_0 was subtracted from the BMI z-score at T_1, and divided by the time in years between the two BMI measurements. By doing so, the dependent variable reflected the mean change in BMI z-score per year, between T_0 and T_1. The second time period (arrow 2 in Figure 1) was treated in the same way, but here the BMI z-score at T_1 was subtracted from the BMI z-score at T_2. The fraction of time spent in each of the PA intensity categories was modeled separately. In the first period, relative PA intensity at T_0 was used and in the second period relative PA intensity at T_1 was used (see Figure 1).

A proportion of the children (*n* = 105) contributed to both time periods, depending on the availability of the measurements at each time point. To account for the correlation between these repeated time periods, we performed generalized estimation equation (GEE) analyses with an exchangeable correlation structure. The time period was used as the within-subject variable. In addition, GEE analyses assume that the effect of PA on BMI development is similar for the first and second time period. To test this assumption, the time period was used to test for statistical interaction with PA (time period x PA interaction). The most complete models were adjusted for origin of BMI measurement (research assistant/parents), cycling, swimming, season, paternal BMI, maternal BMI, and recruitment group (conventional/alternative). Because of optimal readability of Table 2 and realistic increments in PA in children (i.e. 5% roughly corresponds to 30 minutes per day), a PA increment of 5% was chosen to correspond to BMI z-score development.

Randomness of missing values in the covariates (i.e. cycling, swimming, maternal BMI and paternal BMI) was checked by Little's missing completely at random tests, and accompanying missing value analyses. Since none of the covariates with missing values showed strong deviations from the completely at random scenario, all missing values were imputed using multiple regression imputations. In total, 76 missing values of covariates were imputed. The percentage of imputed values per covariate at T_1 ranged between 0.6% for maternal BMI, and 10.7% for cycling and swimming.

Analyses were stratified for weight status at the first measurement of the time period (i.e. initial weight status), as the effect of PA on the development of BMI was expected to be more favorable in children with a high initial weight status, compared to those with a low initial weight status. Due to statistical power arguments, relative lean weight status was defined as the 25th percentile of our study sample and relative heavier weight status was defined as the 75th percentile. Subsequently, children equal to or below the 25th percentile were defined as 'leaner', and children equal to or above the 75th percentile were defined as 'heavier'.

The effect of potential confounders was checked by inspecting the difference in unstandardized regression coefficients of the PA variable, in absence versus presence of the individual confounder. A confounding effect was considered when the unstandardized beta values differed by ≥ 10%, or when the confounder was considered to be essential to the study design (i.e. recruitment group). Potential effect modifiers (i.e. age x PA, gender x

PA and time period x PA) were checked separately from the regression coefficients of the interaction terms, in a complete model containing the main effects and the interaction term. When effect modification was not statistically significant, the interaction term was deleted from the model. When statistically significant interaction was present, we subsequently stratified the analyses. The theoretically considered interaction between initial weight status and PA was stratified irrespective of significance of the interaction term. Goodness of fit statistics were computed to compare models. In all analyses, statistical significance was assumed at $p < 0.05$.

Results

In total, 334 children provided valid PA measurements at T_0, and 297 of these participants also provided valid BMI scores at T_0 and T_1. At T_1, 317 children provided valid PA measurements, and 278 of these participants also provided valid BMI scores at T_1 and T_2. Children participating in either period 1, 2, or both periods were comparable with the total KOALA Birth Cohort (*N* = 2834) in terms of gender (49.7% versus 51.2% boys, respectively), and recruitment group (87.7% versus 82.7% participants with a conventional lifestyle, respectively). In total, 105 participants provided valid measurements for all PA and BMI variables.

Participant characteristics

The characteristics of PA behavior and BMI measurements are presented in Table 1. The mean duration of the first period was a little longer than two years (mean age at T_0: 4.86 years; mean age at T_1: 7.22 years for both boys and girls), while the mean duration of the second period was a little shorter than two years (mean age at T_1: 7.21 years for boys and 7.12 years for girls; mean age at T_2: 9.09 years for boys and 9.04 years for girls) (Table 1). At both T_0 (i.e. baseline period 1) and T_1 (i.e. baseline period 2), boys spent a somewhat higher percentage of time on light PA and MVPA than girls, but in boys, light and MVPA showed more variation (higher standard deviations, Table 1). Except for T_2, boys showed slightly lower BMI z-scores than girls. At all times the study participants were somewhat leaner than the Dutch reference population (BMI z-scores below 0, with the exception of girls at T_0, BMI z-score +0.02).

The leaner category corresponded to ≤ -0.70 BMI score standard deviations, and the heavier category corresponded to ≥ +0.42 BMI score standard deviations. In total, 63 boys (22.3%) and 81 girls (27.7%) were classified as heavier, whereas 74 boys (26.1%) and 71 girls (24.3%) were classified as leaner. Boys and girls did not differ significantly in terms of BMI z-scores within all periods. All remaining participants were classified as normal weight. When this classification was compared against the international obesity taskforce (IOTF) thresholds, 46.20% of leaner children and 31.25% of heavier children were classified as normal weight according to the IOTF (4).

Table 1: Timing and results of measurements of physical activity and Body Mass Index

	Baseline		Follow-up	
	boys	girls	boys	girls
First period	**T_0 (*n* = 150)**	**T_0 (*n*=147)**	**T_1 (*n*=150)**	**T_1 (*n*=147)**
% time spent in light: mean (SD)	46.19 (5.42)	44.37 (4.53)	-	-
% time spent in MVPA: mean (SD)	7.97 (2.73)	7.19 (2.38)	-	-
Age at measurement: mean (SD)	4.86 (0.34)	4.86 (0.31)	7.22 (0.38)	7.22 (0.35)
BMI z-score: mean (SD) *	-0.07 (0.84)	0.02 (0.92)	-0.26 (0.94)	-0.20 (0.93)
Second period	**T_1 (*n*=133)**	**T_1 (*n*=145)**	**T_2 (*n*=133)**	**T_2 (*n*=145)**
% time spent in light: mean (SD)	39.88 (5.04)	39.19 (3.90)	-	-
% time spent in MVPA: mean (SD)	8.00 (2.49)	7.32 (2.34)	-	-
Age at measurement: mean (SD)	7.21 (0.47)	7.12 (0.39)	9.09 (0.67)	9.04 (0.65)
BMI z-score: mean (SD) *	-0.26 (0.99)	-0.16 (0.90)	-0.03 (0.97)	-0.07 (0.96)

Values are presented as mean $\pm$ SD. *: standardized against the age and gender specific reference values of the Fourth Dutch Growth Study (11).

Longitudinal relationship between PA behavior and BMI development

First, the effect of potential effect modifiers (age x PA, gender x PA and period x PA) was checked. We found that interaction with PA was not statistically significant for age and period ($p > 0.05$ for all PA categories). Gender significantly interacted with PA in heavier children ($p < 0.05$ for all PA categories except MVPA), and normal weight children ($p < 0.05$ for MVPA). Consequently, we decided to perform both pooled (top part of Table 2) and stratified GEE analyses for gender, and identify significant gender interactions with a dagger (see Table 2).

In heavier children, a 5% increment of MVPA was associated with a 0.16 decrease in BMI z-score, and this was of similar size in boys (0.17) and girls (0.14), and statistically significant in both (Table 2). In heavier boys, a 5% increment of light PA was also related to a statistically significant decrease of 0.13 BMI z-scores per year. When combining light PA and MVPA into total PA, this amounted to a 0.11 BMI decrease in heavier boys for a 5% increment in total PA. In normal weight boys, only MVPA was associated with a decrease of BMI z-score. Girls generally did not show any decrease in BMI related to PA in the adjusted models, except for MVPA in heavier girls (similar to boys as noticed above).

Table 2: Associations between physical activity (PA) level and change in BMI z-scores between age 4-5 and 8-9 years, stratified for baseline weight status.

Physical activity level		**Total PA** beta (95% CI)	**Light PA** beta (95% CI)	**MVPA** beta (95% CI)
Boys and girls ‡				
Leaner (*n*=145)	Unadjusted	-0.02 (-0.07 to 0.03)	-0.03 (-0.09 to 0.02)	0.03 (-0.09 to 0.14)†
	Adjusted	-0.01 (-0.06 to 0.04)	-0.03 (-0.08 to 0.02)	0.04 (-0.07 to 0.15)
Normal-weight (*n*=286)	Unadjusted	0.02 (-0.01 to 0.06)	**0.05 (0.002 to 0.09)**	-0.04 (-0.11 to 0.03)
	Adjusted	0.01 (-0.03 to 0.05)	0.03 (-0.01 to 0.07)	-0.05 (-0.13 to 0.02)
Heavier (*n*=144)	Unadjusted	-0.04 (-0.09 to 0.00)†	-0.03 (-0.08 to 0.03)†	**-0.13 (-0.26 to -0.01)**
	Adjusted	**-0.06 (-0.11 to -0.02)**†	-0.05 (-0.11 to 0.004)†	**-0.16 (-0.27 to -0.04)**
Boys				
Leaner (*n* = 74)	Unadjusted	-0.02 (-0.09 to 0.05)	-0.04 (-0.12 to 0.03)	0.05 (-0.13 to 0.23)†
	Adjusted	0.00 (-0.06 to 0.06)	-0.03 (-0.09 to 0.04)	0.12 (-0.06 to 0.31)
Normal-weight (*n* = 146)	Unadjusted	-0.01 (-0.08 to 0.06)	0.03 (-0.04 to 0.10)	**-0.11 (-0.22 to -0.01)**
	Adjusted	-0.01 (-0.08 to 0.06)	0.03 (-0.05 to 0.10)	**-0.13 (-0.24 to -0.02)**
Heavier (*n* = 63)	Unadjusted	**-0.10 (-0.17 to -0.02)**†	**-0.10 (-0.19 to -0.01)**†	-0.17 (-0.36 to 0.01)
	Adjusted	**-0.11 (-0.18 to -0.04)**†	**-0.13 (-0.23 to -0.04)**†	**-0.17 (-0.33 to -0.004)**
Girls				
Leaner (*n* = 71)	Unadjusted	-0.01 (-0.07 to 0.04)	-0.02 (-0.10 to 0.05)	-0.00 (-0.14 to 0.13)†
	Adjusted	-0.01 (-0.08 to 0.06)	-0.02 (-0.11 to 0.07)	0.02 (-0.12 to 0.16)
Normal-weight (*n* = 140)	Unadjusted	**0.05 (0.004 to 0.09)**	**0.07 (0.01 to 0.12)**	0.04 (-0.05 to 0.13)
	Adjusted	0.04 (-0.01 to 0.08)	0.04 (-0.01 to 0.10)	0.06 (-0.04 to 0.16)
Heavier (*n* = 81)	Unadjusted	-0.01 (-0.06 to 0.04)†	0.01 (-0.05 to 0.07)†	-0.10 (-0.24 to 0.04)
	Adjusted	-0.01 (-0.05 to 0.05)†	0.03 (-0.05 to 0.10)†	**-0.14 (-0.27 to -0.01)**

Regression coefficients (beta) represent the change in BMI z-scores per year for an absolute increment of 5% of physical activity (PA). Results of Generalized Estimations Equations linear regression with PA measured at age 4-5 years and 6-7 years, and BMI z-score (standardized for age and sex) measured at age 4-5 years, 6-7 years and 8-9 years, using an exchangeable correlation structure to account for the repeated measurements. Since 105 participants were measured at both periods, this table represents the number of measurements instead of participants. Unadjusted models: only PA and time (age period) in the model; adjusted models: adjusting for origin of BMI z-score, bicycling, swimming, season, recruitment group, paternal- and maternal BMI. Weight status was categorized at the first measurement of BMI available at age 4-5 or 6-7 years (baseline), into leaner (lowest quartile), heavier (highest quartile) and normal-weight (middle two quartiles) children). Bold numbers indicate statistical significance of the regression coefficient at $p < 0.05$, †: gender interaction term was statistically significant at $p < 0.05$. ‡: Included an interaction term for gender x period in the adjusted models.

Discussion

This study showed that increments of MVPA across a period of approximately 2.5 years were related to a significant decrease in BMI z-scores in heavier children. In heavier boys, increments in light PA were also related to a significant decrease in BMI z-scores, and in normal weight boys, somewhat similar decreases were found.

Our finding concerning the association between MVPA and BMI in heavier children is supported by previous studies (17, 22), although more recent evidence is less clear for this association (40). As high BMI z-scores and low MVPA percentages at baseline are likely to subsequently regress to a mean value because of natural causes, this finding may also be influenced by the regression to the mean principle. However, the differential effects of PA in initially leaner, normal weight and heavier subgroups of children, between boys and girls, and within different intensities of PA, strengthen the impression that these results are not an artificial relationship caused by regression to the mean.

In this study, the intensity of PA was based on accelerometry-based counts. One should bear in mind that equal levels of MVPA do not necessarily mean equal energy expenditure. A disadvantage of accelerometers is their inability to detect arm movements and external work (8). Thereby they underestimate the energy cost of certain activities, such as rowing, cycling, weight lifting or using the stairs. In addition, the energy expenditure depends on the child's motor ability or physical fitness. Specifically, a physically fit child with high motor abilities may expend less energy during PA of equal intensity, compared to their relatively unfit counterparts. The advantage of using PA intensity levels instead of energy expenditure is that PA is not dependent upon these factors. Future studies should use objectively measured PA, accompanied by measures of activities that accelerometers are unable to detect.

The differential effect of PA on BMI development between boys and girls is supported by one study (2). Although it is nowadays well understood that most boys spend more time being physically active than girls (38), it is unknown why girls seem to be less sensitive to changes in PA. Future studies are therefore encouraged to investigate this more thoroughly.

In contrast to MVPA, light PA showed somewhat weaker associations with BMI development. This discrepancy is supported by several studies (10, 16, 28) which generally reported that PA of the highest intensity (i.e. vigorous PA) was more strongly related to decreases in adiposity compared to less intensive PA. One study showed that the effect of MVPA was independent of the time spent sedentary (33), which may indicate that vigorous PA may provide more benefit than just increasing energy expenditure.

Strengths and weaknesses

One of the strengths of this study is the longitudinal design, containing two periods of repeated measurements, representing a period in childhood that included an important developmental stage in childhood adiposity (27). In total, 105 children contributed to both time periods, providing accelerometry and anthropometry at three subsequent time points. Accelerometers are considered to be a valid measure of children's daily PA behavior (3). By the parental reports of cycling and swimming we controlled for uncertainty regarding these activity types when using accelerometer measurements. Furthermore, as we measured PA for a minimum of two weekdays and one weekend day, the between-day intraclass reliability coefficient of PA in 4-5 year-old children (irrespective of intensity) was 0.62 when applied for the first three days of measurement. Similarly, the intraclass reliability coefficient for 6-7 and 8-9 year-old children was 0.63 and 0.54, respectively. In addition, we showed that the present sample did not differ significantly from the total KOALA Birth Cohort (*N* = 2834) in terms of gender and recruitment group. In total, 13.3% of the children in our sample had an alternative lifestyle. As these children may be exposed to alternative dietary patterns, the relationship between PA and BMI development may be different in these children. However, we found no evidence for a statistically significant interaction in this relationship. Finally, we controlled for the potential confounding effect of the recruitment group in all analyses. By including these participants, our results are generalizable to a population with diverse views of health and life.

The present study was also prone to some weaknesses. The type of measurement (e.g. parent-reported versus measured height and weight to calculate BMI) may have biased our results. One study comparing measured and parent-reported height and weight on a national scale in the United States, reported that parents of 2-11 year-old children overestimated their child's overweight by underestimating their child's height (1). Another study showed that parents underestimated their child's overweight by underestimating weight and overestimating height (31). In addition, a study that used 64.4% of the total KOALA cohort reported that parents underestimated their 6-7 year-old child's overweight (36). When examining longitudinal associations, this potential bias may be differential, depending on the combination of origins present. For example, a child's height and weight may be measured at 6-7 years and parent-reported at 8-9 years or vice versa. Such differential bias was not possible in the first period, as all participants' height and weight were measured at 4-5 years old. In the second period, we found that the combination of parent-reported and measured anthropometry over time (e.g. parent-reported at baseline versus measured at follow-up) differed between boys and girls and we therefore included this interaction in the adjusted models. Furthermore, the selection of participants to measure (instead of report) was based on the availability of accelerometry at 6-7 years old, and not based on any PA or BMI trait. This was supported by an intraclass correlation coefficient of -0.08 (95% CI = -0.30 to 0.11) between origins from 6-7 and 8-9 years old. Therefore, we can cautiously suggest that it is unlikely that this bias has significantly inflated our results. In addition, as we have adjusted for the origin of the measurements in all analyses, any potential systematic bias was controlled for.

We decided to focus solely on the effect of PA and not to control for energy intake as this would lead to unwanted indirect controlling for PA, and therefore would annul the observed associations. However, as some children compensate MVPA with specific unhealthy dietary habits (e.g. sugar sweetened drinks), this would be interesting to investigate in future studies, but was beyond the scope of the present study.

We used 25th and 75th percentiles for the classification of relative leaner and heavier children, respectively. We were unable to use the IOTF thresholds (4) for classification of overweight, underweight and normal weight because this would have resulted in too small group sizes. This study showed that children with relatively smaller deviations from normal weight can benefit from MVPA.

When interpreting results from accelerometers, some discussion arises concerning thresholds for PA intensities. In the present study, the thresholds of Evenson (12) were used because of the similarity of the age of children in our sample and Evenson's validation study, and the advantage of using one threshold for all age categories. However, Evenson's thresholds are notably lower compared to other thresholds (12). Our results, therefore, may have overestimated the percentage of light PA in children, and underestimated the percentage of sedentary behavior. Some studies suggest that differences in accelerometry thresholds predominantly occur in teenage years (29); other studies suggest that these differences are also present in the age categories in our study sample (26, 38). However, because the age range was rather narrow in our study sample, the magnitude of this potential bias was expected to be small. In addition, one may suggest that small but significant differences exist between the two Actigraph accelerometer models used in our study. One previous study found that the GT1M model reported an average 9% lower counts per epoch compared to the 7164 model. However, both models did not significantly differ when counts were conceptualized as time spent in moderate or vigorous category (5). This comparability is supported by two other studies, of which one reported no differences at all (18), and the other reported only slight differences that were not meaningful in activity intensity classification (19). If one did suppose that differences existed, then this potential bias would be randomly distributed over the entire sample, as we were unaware of a child's BMI when handing out the accelerometers. Discrepancies between the two Actigraph models are therefore unlikely to have significantly biased our results.

Impact

A 5% daily increment of MVPA per year (i.e. 32.5 minutes) may be difficult for children to achieve. Alternatively, a 1% daily increment of MVPA per year corresponds to only 6.5 minutes. In this case, a heavier child has to spend approximately 6.5 more minutes per day in MVPA in order to achieve an average subsequent decrease of 0.03 BMI z-scores per year. Even though this is a small decrease, when sustained through entire childhood, such a decrease may become relevant for the primary prevention of obesity. In conclusion, we found that increments of MVPA were associated with decreases in BMI z-score in heavier children, both boys and girls.

Acknowledgments

This study was partially supported by the Netherlands Heart Foundation, (grant no. 2008B112 to E.F.C. Sleddens). Results of the present study do not constitute endorsement by ACSM. The authors declare that they have no competing interest.

References

1 Akinbami LJ, Ogden CL. Childhood overweight prevalence in the United States: the impact of parent-reported height and weight. Obesity. 2009;17(8):1574-80.

2 Basterfield L, Adamson AJ, Frary JK, Parkinson KN, Pearce MS, Reilly JJ. Longitudinal study of physical activity and sedentary behavior in children. Pediatrics. 2011;127(1):24-30.

3 Cliff DP, Reilly JJ, Okely AD. Methodological considerations in using accelerometers to assess habitual physical activity in children aged 0-5 years. Journal of Science and Medicine in Sport. 2009;12(5):557-67.

4 Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. British Medical Journal. 2000;320(7244):1240.

5 Corder K, Brage SR, Ramachandran A, Snehalatha C, Wareham N, Ekelund U. Comparison of two Actigraph models for assessing free-living physical activity in Indian adolescents. Journal of Sports Sciences. 2007;25(14):1607-11.

6 Cremers E, Thijs C, Penders J, Jansen E, Mommers M. Maternal and child's vitamin D supplement use and vitamin D level in relation to childhood lung function: the KOALA Birth Cohort Study. Thorax. 2011;66(6):474-80.

7 Daniels SR. The consequences of childhood overweight and obesity. Future of Children. 2006;16(1):47-67.

8 de Vries SI, Bakker I, Hopman-Rock M, Hirasing RA, van Mechelen W. Clinimetric review of motion sensors in children and adolescents. Journal of Clinical Epidemiology. 2006;59(7):670-80.

9 Dietz W. Critical periods in childhood for the development of obesity. American Journal of Clininical Nutrition. 1994;59(5):955-9.

10 Ekelund U, Sjöström M, Yngve A, Poortvliet E, Nilsson A, Froberg K, et al. Physical activity assessed by activity monitor and doubly labeled water in children. Medicine & Science in Sports & Exercise. 2001;33(2):275-81.

11 Erickson SJ, Robinson TN, Haydel KF, Killen JD. Are overweight children unhappy?: Body mass index, depressive symptoms, and overweight concerns in elementary school children. Archives of Pediatrics and Adolescent Medicine. 2000;154(9):931.

12 Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. Journal of Sport Sciences. 2006;24(14):1557-65.

13 Fredriks AM, van Buuren S, Wit JM, Verloove-Vanhorick S. Body index measurements in 1996–7 compared with 1980. Archives of Disease in Childhood. 2000;82(2):107-12.
14 Goran MI. Energy expenditure, body composition, and disease risk in children and adolescents. Proceedings of Nutrition Society. 1997;56(1B):195-209.
15 Goran MI, Gower BA, Nagy TR, Johnson RK. Developmental changes in energy expenditure and physical activity in children: evidence for a decline in physical activity in girls before puberty. Pediatrics. 1998;101(5):887-91.
16 Gutin B, Owens S. The influence of physical activity on cardiometabolic biomarkers in youths: a review. Pediatric Exercise Science. 2011;23(2):169-85.
17 Jago R, Baranowski T, Baranowski JC, Thompson D, Greaves KA. BMI from 3-6 y of age is predicted by TV viewing and physical activity, not diet. International Journal of Obesity and Related Metabolic Disorders. 2005;29(6):557-64.
18 John D, Tyo B, Bassett DR. Comparison of four ActiGraph accelerometers during walking and running. Medicine & Science in Sports & Exercise. 2010;42(2):368.
19 Kozey SL, Staudenmayer JW, Troiano RP, Freedson PS. A comparison of the ActiGraph 7164 and the ActiGraph GT1M during self-paced locomotion. Medicine & Science in Sports & Exercise. 2010;42(5):971.
20 Mattocks C, Tilling K, Ness A, Riddoch C. Improvements in the measurement of physical activity in childhood obesity research; lessons from large studies of accelerometers. Pediatrics. 2008; (Pediatric Obesity Special Issue) 27-36.
21 Metcalf BS, Voss LD, Hosking J, Jeffery AN, Wilkin TJ. Physical activity at the government-recommended level and obesity-related health outcomes: a longitudinal study (early bird 37). Archives of Disease in Childhood. 2008;93(9):772-7.
22 Moore LL, Gao D, Bradlee ML, Cupples LA, Sundarajan-Ramamurti A, Proctor MH, et al. Does early physical activity predict body fat change throughout childhood? Preventive Medicine. 2003;37(1):10-7.
23 Must A, Tybor DJ. Physical activity and sedentary behavior: a review of longitudinal studies of weight and adiposity in youth. International Journal of Obesity. 2005;29:S84-S96.
24 Pate RR, Pratt M, Blair SN, Haskell WL, Macera CA, Bouchard C, et al. Physical activity and public health: a recommendation for the centers for disease control and prevention and the American college of sports medicine. Journal of the American Medical Assocation. 1995;273(5):402-7.
25 Prentice AM. Obesity-the inevitable penalty of civilisation? British Medical Bulletin. 1997;53(2):229-37.
26 Riddoch CJ, Leary SD, Ness AR, Blair SN, Deere K, Mattocks C, et al. Prospective associations between objective measures of physical activity and fat mass in 12-14 year old children: the Avon Longitudinal Study of Parents and Children (ALSPAC). British Medical Journal. 2009;339.

27 Rolland-Cachera M, Deheeger M, Bellisle F, Sempe M, Guilloud-Bataille M, Patois E. Adiposity rebound in children: a simple indicator for predicting obesity. American Journal of Clinical Nutrition. 1984;39(1):129-35.
28 Ruiz JR, Rizzo NS, Hurtig-Wennlof A, Ortega FB, Warnberg J, Sjostrom M. Relations of total physical activity and intensity to fitness and fatness in children: the European Youth Heart Study. American Journal of Clinical Nutrition. 2006;84(2):299-303.
29 Sallis JF. Age-related decline in physical activity: a synthesis of human and animal studies. Medicine & Science in Sports & Exercise. 2000;32(9):1598-600.
30 Sallis JF, Saelens BE. Assessment of physical activity by self-report: status, limitations, and future directions. Research Quarterly for Excercise and Sport. 2000;71(S2):1-14.
31 Scholtens S, Brunekreef B, Visscher TL, Smit HA, Kerkhof M, Jongste JC, et al. Reported versus measured body weight and height of 4-year-old children and the prevalence of overweight. European Journal of Public Health. 2007;17(4):369-74.
32 Schonbeck Y, Talma H, van Dommelen P, Bakker B, Buitendijk SE, HiraSing R, et al. Increase in prevalence of overweight in Dutch children and adolescents: a comparison of nationwide growth studies in 1980, 1997 and 2009. PloS One. 2011;6(11).
33 Steele RM, van Sluijs EM, Cassidy A, Griffin SJ, Ekelund U. Targeting sedentary time or moderate- and vigorous-intensity activity: independent relations with adiposity in a population-based sample of 10-y-old British children. American Journal of Clinical Nutrition. 2009;90(5):1185-92.
34 Telama R, Yang X, Viikari J, Välimäki I, Wanne O, Raitakari O. Physical activity from childhood to adulthood: a 21-year tracking study. Am J Prev Med. 2005;28(3):267-73.
35 Thompson D, Wolf AM. The medical-care cost burden of obesity. Obesity Reviews. 2001;2(3):189-97.
36 Timmermans S, Mommers M, Gubbels J, Kremers SP, Stafleu A, Stehouwer CD, et al. Maternal smoking during pregnancy and childhood overweight and fat distribution: the KOALA Birth Cohort Study. Pediatric Obesity. 2013.
37 Trost SG, Pate RR, Freedson PS, Sallis JF, Taylor WC. Using objective physical activity measures with youth: how many days of monitoring are needed? Medicine & Science in Sports & Exercise. 2000;32(2):426-31.
38 Trost SG, Pate RR, Sallis JF, Freedson PS, Taylor WC, Dowda M, et al. Age and gender differences in objectively measured physical activity in youth. Medicine & Science in Sports & Exercise. 2002;34(2):350-5.
39 Whitaker RC, Pepe MS, Wright JA, Seidel KD, Dietz WH. Early adiposity rebound and the risk of adult obesity. Pediatrics. 1998;101(3):462.

40 Wilks D, Besson H, Lindroos A, Ekelund U. Objectively measured physical activity and obesity prevention in children, adolescents and adults: a systematic review of prospective studies. Obesity Reviews. 2011;12(5):119-29.

CHAPTER 3

Moderators of the relationship between physical activity enjoyment and physical activity in children

This chapter has been published as:

Remmers T, Sleddens EF, Kremers SP, Thijs C. Moderators of the relationship between physical activity enjoyment and physical activity in children. Journal of Physical Activity and Health. 2015;12(8):1066-73.

Abstract

Background: Physical activity (PA) enjoyment may be an important determinant of long-term habitual, self-sustained PA behavior in children. The objective of the current study was to contribute toward a better understanding of how children's PA enjoyment is associated with PA behavior by examining the influence of age, gender, BMI, and impulsivity as theoretically hypothesized moderators of this relationship.
Methods: PA was measured in 171 children (77 boys, 91 girls) using accelerometers, and PA enjoyment was assessed with the validated Physical Activity Enjoyment Scale in 9-year-old children from the KOALA Birth Cohort Study, the Netherlands. Linear regressions were fitted. Moderation was tested by adding interaction terms between PA enjoyment and the potential moderators.
Results: We found a significant 3-way interaction (PA enjoyment × gender × impulsivity) for all intensities of PA behavior. In boys, impulsivity strengthened the relationship between PA enjoyment and PA behavior, whereas in girls impulsivity weakened this relationship.
Conclusion: In girls, this may be explained by the relative automatic occurrence of PA behavior in impulsive girls (independent of PA enjoyment). In boys, the possibility that impulsivity is associated with hyperactivity may explain this moderation. The current study may encourage researchers to investigate these interactions in future studies.

Introduction

Effects of interventions that attempt to increase children's physical activity (PA) are often limited to short-term improvements. A child compensating intense PA with more sedentary behavior is a major paradox in these studies (1). In contrast, determinants of long-term, self-sustained, habitual PA behavior may give insight in how long-term increases of self-sustained PA are most likely to be achieved. Enjoyment of the activity itself, instead of external pressure or rewards, is a key prerequisite of intrinsic motivation, which is in turn related to habit formation and self-sustainment (2). Therefore, PA enjoyment may be an important determinant of long-term habitual, self-sustained PA behavior in children. Increments in this type of PA may provide beneficial effects to cardio respiratory, musculoskeletal, and morphological aspects of children's physical fitness. Studies that examine the relationship between PA enjoyment and PA behavior can reinforce theoretical frameworks of future observational studies and PA interventions.

Few studies previously investigated relationships between PA enjoyment and children's PA behavior (3-8). Subjective measurements of PA (e.g. parental reports) are prone to significant measurement errors in children (9), as children's PA behavior is considered less structured (e.g. short bouts of intense PA) and shows considerable daily variation compared to adults (10). We identified only two studies that examined PA enjoyment in relation with objectively assessed PA behavior (i.e. accelerometers) (3,5), and their results are contradictory. While Wenthe et al. (2009) found that PA enjoyment was related with PA behavior in adolescent girls, Lawman (2011) found no such association in 11 year-old underserved boys and girls.

The ecological perspective of heath behaviors and several social-environmental models purpose that the influences of social environmental factors depend on personal characteristics (e.g. age, gender) and physical environmental factors (e.g. accessibility) (11,12). Thus, for a better understanding of the influence and implications of PA enjoyment on PA behavior, personal characteristics that may moderate the relationship between PA enjoyment and PA behavior are of interest. First, *gender* differences may be important, as objective measurements showed that girls are generally less active (13,14) and girls display a considerable decline in activity energy expenditure before puberty (10). One study found that gender differences in determinants of PA (e.g. family support, physical access, crime) were indeed related with gender differences in objectively measured PA (3). In addition, boys have different PA preferences than girls, with boys preferring more high intensity activities (15), potentially leading to differences in participation of especially high intensity PA. However, it is unknown whether these gender differences may also exist in PA enjoyment because PA is assessed across various exercise and PA modalities. Second, several studies reported patterns of decreased PA while children get older (14,16). These *age*-related PA declines are especially worrisome if maintained over longer periods of time and a sustainable determinant of PA (i.e. PA enjoyment) may predict this long-term development of child PA (17). Age may attenuate the association between PA enjoyment and PA behavior in a way that older children may

be more constrained by external factors (e.g. homework) in their engagement in PA, irrespective of their PA enjoyment. Third, one study showed that an elevated *Body Mass Index* (BMI) may lead to weight-criticism and lower PA levels as a result of avoidant coping (18). In this way, BMI may attenuate the association between PA enjoyment and PA behavior as heavier children may experience limitations to perform PA by their overweight. Finally, several conceptual frameworks postulate that the relationship between the social environmental factors and behavior can also be moderated by personality traits (11,19). A personality trait that might be of importance in this case is the degree of automaticity as this moderates a person's reaction to the environment, and thus plays a considerable role in the behavior of adults and children (20,21). In addition, high tendencies towards automaticity/spontaneity (i.e. *impulsivity*) have already been established as a key moderating factor of influences on child snacking behavior (22,23). PA in children is often characterized as spontaneous (24). Therefore, impulsivity may attenuate the association between PA enjoyment and PA behavior, as in impulsive children PA may occur rather automatically without involvement of cognition. We addressed the following research question: what is the association between PA enjoyment and objectively measured PA behavior and are 1) gender, 2) age, 3) BMI, and 4) impulsivity of the child moderators in this relationship?

Methods

Study design and participants

This study was embedded in the KOALA Birth Cohort Study. The cohort was recruited among healthy pregnant women in the general population via obstetric practices (conventional recruitment group, n=2343); and partly in healthy pregnant women recruited among alternative lifestyle channels, such as organic food shops and anthroposophic doctors' practices (alternative recruitment group, n=491) (25,26). From the total KOALA-cohort, 584 children were eligible and selected by the availability of previous accelerometer measurements between ages 4-5 years (27) and/or 6-7 years at the occasion of home visits for lung function testing (26). At child's age of 8-9 years old, we measured PA behavior by accelerometry, and PA enjoyment by questionnaire. For these measurements, we excluded children with asthma diagnosis (*n*=33), growth hormone medication use (*n*=1), loss-to-follow up (*n*=11), and residing ≥ 30 kilometers from the nearest study location (*n*=69). The flow of participants is presented in Figure 1. Finally, 171 participants provided valid accelerometry and data PA enjoyment at 8-9 years old. All parents gave written informed consent. The present study was approved by the Medical Ethics Committee of Maastricht University Medical Center+.

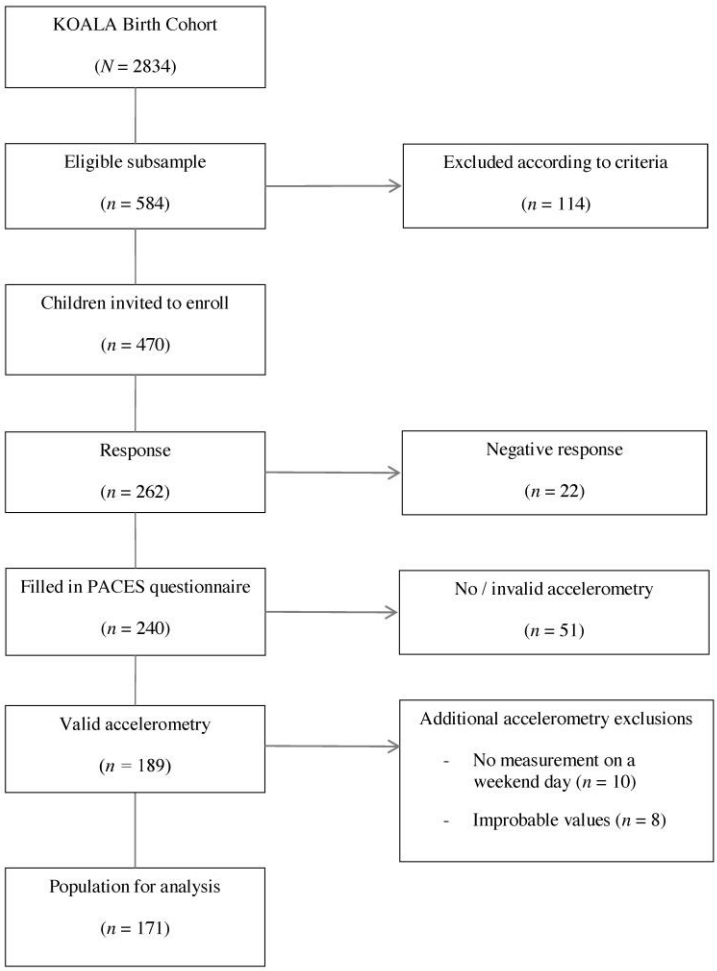


Figure 1: Flowchart

Measurements

PA enjoyment

We measured PA enjoyment by the self-reported, Dutch translation of the Physical ACtivity Enjoyment Scale (PACES), originally designed for adults by Kendzierski and DeCarlo (1991) (28). The original PACES is a single factor, 18-item scale to asses PA enjoyment across various exercise and PA modalities, using 7-point Likert response scales. Factorial and construct validity of a slightly adjusted 16 item 5-point Likert response scale version of the PACES was evaluated in adolescent girls (29). In this study, factorial validity was investigated by exploratory and confirmatory factor analyses, and acceptable fit for the model was reported (29). In addition, after making negligible modifications from the version of Motl et al. (2001), the reliability and validity of the PACES were also evaluated

in elementary school children (8). This study showed good overall reliability (α= 0.87, *n*= 511) and acceptable internal consistency of the PACES (corrected item-total correlations (CITCs) ranged from 0.26 to 0.71). Confirmatory factor analyses confirmed findings of Motl et al. (2001); showing acceptable fit of the factor (8). The Dutch translated PACES, as used in the present study, was developed, pretested, and validated in a larger sample of 8 to 10 years old children in Maastricht, the Netherlands (30). In this validation study, two items had more than 10% missing values, because some children were not familiar with the used terminology (i.e. "exciting" and "getting a kick out of it"). These items were excluded from further analyses, resulting in 14 remaining items, in which a mean score was calculated. In the exploratory factor analysis most of the items loaded on one factor with acceptable factor loadings. Only one item (0.24) did not meet the threshold of 0.30. For the current study we decided to keep all 14 items. Correlations between the sum scores of the PACES and a validated measure of motivational regulation (e.g. BRePAC) was found to comply with the expected pattern (30). In addition, we evaluated the internal consistency of our own sample by Cronbach's alpha and CITCs (30). Cronbach's alpha for the PACES scale in the present sample was 0.88. Following the guidelines proposed by Nunnally & Bernstein (1994) to define the minimum levels of item-scale correlations that are acceptable, we used cut-off points of 0.15 and 0.30 (31). Correlations above 0.30 are considered good and correlations below 0.15 are considered unreliable since they would indicate lack of homogeneity of the items within a scale. CITCs ranged from 0.49 to 0.75 for 13 items, indicating homogeneity of the items. One item ("that makes me sad") fell below the value of 0.30, but still above the critical cut-off point of 0.15. We explicitly instructed the children to complete the questionnaire individually. As the PACES mean scores were negatively skewed, we dichotomized this variable using a median split (≤4.29 versus >4.30).

PA behavior

We measured PA behavior by accelerometry with the uniaxial ActiGraph 7164 and GT1M accelerometers (ActiGraph, Fort Walton Beach, FL). We instructed participants to wear the ActiGraph during daytime on the right hip for 7 days, and only remove the accelerometer during activities were water was involved, such as swimming. To investigate the influence of swimming, parents were asked to report this in a diary. Although we made all efforts to prevent occurrence of measurements in non-regular weeks, we excluded occasional measurement-days within holidays from further analyses. We initialized the ActiGraph to capture the counts every 15 seconds (epochs). We considered periods of 60 minutes containing no accelerometry counts as non-wearing time and we therefore subtracted these measurements from the registration time. We considered at least 400 minutes of registration time, for a minimum of 2 week days and one weekend day of measurement.

We used the thresholds of Evenson (32) to distinguish between sedentary behavior (0-25 counts per epoch), PA at light (26-573 counts per epoch), moderate (574-1002 counts per epoch), and vigorous intensity (≥1003 counts per epoch). Subsequently, we combined the light, moderate and vigorous PA intensities in the 'active' category. The moderate and

vigorous categories were summed in moderate to vigorous PA (MVPA) (4). In all analyses, PA was conceptualized as the percentage of time spent in the various intensities relative to the total registration time. To be able to capture the intermittent, spontaneous nature of child's PA, we computed the number of PA bouts. In the present study, a bout of PA consists of at least 1 minute of vigorous PA (i.e. ≥1003 counts per epoch). We used a drop time of 15 seconds, which means that at least three out of four epochs in one minute should be of vigorous PA. Children's PA is dependent of season (i.e. more PA in spring and summer) (33). Therefore, we computed meteorological seasons at which the PA measurement commenced, and entered these as independent variables in subsequent analyses. We visually inspected the normality assumptions of the percentage active, light, MVPA, and distributions showed to be normal. The number of PA bouts was positively skewed, we therefore we used its natural logarithm for further analyses.

Impulsivity

Impulsivity is generally defined as a relative inability to plan, control and execute reasoned action (34). For the measurement of impulsivity we used the Impulsivity Scale from the child-reported version (from age 7 onwards) of the Temperament in Middle Childhood Questionnaire (TMCQ) (35,36). This scale is based on the impulsivity dimension of the Child Behavior Questionnaire (CBQ) (37). The CBQ is a larger instrument that assesses temperamental traits of children between three and six years old (37). The impulsivity scale of the TMCQ was previously validated against the CBQ within a sample from the KOALA Birth Cohort study. This validation study supported the applicability of the impulsivity scale as impulsivity was highly related to surgency/extraversion, the higher-order temperamental trait characterized by impulsive and active behavior (36). In the TMCQ, children were asked to respond to 13 statements (e.g. 'I decide what to do quickly and then go and do it right away') describing impulsive behaviors and had to choose the answer that applied to them most, using a 5-point Likert scale ranging from 1 (Never) to 5 (Always). Cronbach's alpha for the impulsivity scale in the present sample was 0.69. Corrected-item total correlations ranged from 0.20 to 0.56 for 13 items, indicating sufficient homogeneity of the items (31).

Body Mass Index

We measured child's body weight using an electronic scale (CAS personal scale, HE-5) while wearing light sports-clothes, excluding shoes. Height was measured with accuracy of 0.5 centimeters using a telescopic stadiometer (Leicester height measure), without shoes and hair ornaments. Subsequently, we calculated BMI as weight divided by height squared (kg/m^2) and we calculated BMI z-scores according to reference values of the fourth Dutch growth study, to standardize for age and gender (38).

Statistical analyses

Characteristics of the population for analysis were evaluated with descriptive statistics. As PA behaviors were shown to differ considerably between boys and girls (39), we explored this with Chi-square tests and *t*-tests for categorical and continuous levels of measurements, respectively.

To evaluate the crude association between PA enjoyment and PA behavior, we first modeled linear regression analyses, with several components of PA behavior (i.e. percentages of active, light, MVPA intensities, and number of PA bouts) as dependent variables. PA enjoyment (dichotomous) served as the independent variable. Second, we fitted linear regressions containing all main effects in the model (i.e. gender, age, BMI, and impulsivity) for each of the PA behaviors as dependent variables. Third, we inspected the interaction of each of these main effects separately. We checked linearity and homoscedasticity by plotting standardized residual versus standardized predicted residuals, and inspected the accompanying histogram. In all studied models, the assumptions were met. We tested for moderation by computing an interaction term between PA enjoyment and the potential moderators (i.e. age, BMI, and impulsivity) a priori for boys and girls separately. Based on these results, we stratified our final analyses based on statistically significant interaction terms ($p < 0.10$).

Results

Participant characteristics

The total sample consisted of 80 boys and 91 girls with a mean age of 9.17 (SD=0.63) years, as presented in Table 1. Average PA enjoyment was similar for boys and girls (PACES mean 4.19 versus 4.20). While time spent in light activity was similar between boys and girls (Table 1), boys showed a significantly higher percentage of time spent in MVPA than girls, amounting to a higher percentage of time spent active per day ($p <0.05$). The average number of PA bouts per day was also higher in boys than girls ($p <0.05$). Gender differences were small and not statistically significant for BMI and impulsivity (Table 1).

Table 1. Descriptive characteristics of the study sample.

	Boys		Girls	
	n	Mean (SD)	*n*	Mean (SD)
Age (years)	80	9.2 (0.6)	91	9.1 (0.7)
Recruitment group (% alternative)	5	6%	9	10%
Low maternal education	8	10%	9	10%
Mid-low maternal education	25	31%	35	39%
Mid-high maternal education	44	55%	45	50%
High maternal education	3	4%	2	2%
PACES mean (1.00 – 5.00)	80	4.2 (0.3)	91	4.2 (0.4)
PACES (below median ≤ 4.2857)	36	45.0%	38	41.8%
Days of PA measurement	80	6.7 (1.0)	91	6.5 (0.9)
% time spent active per day	80	**49.8 (5.0)**	91	**48.0 (4.4)**
% time spent in light PA per day	80	39.9 (3.4)	91	39.7 (3.3)
% time spent MVPA per day	80	**10.0 (2.9)**	91	**8.1 (2.6)**
PA Bouts (average number per day)	80	**7.1 (4.3)**	91	**4.9 (3.6)**
PA measurements in autumn	8	**10.0%**	22	**24.2%**
PA measurements in spring	37	46.3%	36	39.6%
PA measurements in summer	35	43.8%	33	36.3%
BMI (z-scores) †	80	-0.14 (0.83)	91	-0.06 (1.00)
Impulsivity mean (1.00 – 5.00)	80	2.6 (0.5)	91	2.5 (0.5)
Impulsivity (≤ 2.5385)	41	51.3%	50	54.9%

† compared with the Fourth Dutch growth study (Fredriks et al., 2000). **Bold** numbers represent a statistical significant gender difference at $p < 0.05$.

PA enjoyment and PA behavior

Table 2 presents the crude and adjusted relationships between PA enjoyment and PA behavior. In boys, PA enjoyment was not related with any level of PA behavior. In girls, however, PA enjoyment was significantly related to higher percentages of active (2.21, 95% CI 0.39 to 4.04) and light PA (1.51, 95% CI 0.14 to 2.88). These significant associations were attenuated in the adjusted models. Thus, although the average regression coefficients were positive indicating more/higher percentages of PA, no statistical significant associations were found.

Moderators of the PA enjoyment – PA behavior relationship

Age and BMI z-score showed no statistically significant interaction with PA enjoyment (data not shown, $p > 0.10$). In contrast, we found impulsivity to interact significantly with PA enjoyment in the relationship with active, MVPA and PA bouts in both boy and girls. As the beta-coefficient of these interactions differed in direction between boys and girls, we further explored this by computing a three-way interaction term in the linear regression model (i.e. PA enjoyment * gender * impulsivity) for the total sample (including boys and girls). The interaction model consisted of the three independent variables (PA enjoyment,

gender and impulsivity), all three pairs of two-way interaction terms, and the three-way interaction term. We tested this with all types of PA. Results showed statistically significant three-way interaction terms for active (*p*= 0.002), light, (*p*= 0.10), MVPA (*p*= 0.001), and PA bouts (*p*= 0.002). Figure 2 gives a graphical presentation of this interaction. Consequently, we stratified our analyses for gender and impulsivity (Table 3).

Table 2. The association between physical activity enjoyment and physical activity behavior for boys and girls.

		% Active	% Light	% MVPA	# PA Bouts
Boys	Crude	0.81 (-1.44 to 3.07)	0.66 (-0.86 to 2.19)	0.14 (-1.17 to 1.46)	-0.14 (-0.49 to 0.22)
	Adjusted ‡	0.69 (-1.60 to 2.97)	0.90 (-0.59 to 2.39)	-0.21 (-1.59 to 1.16)	-0.25 (-0.61 to 0.11)
Girls	Crude	**2.21 (0.37 to 4.05)**	**1.51 (0.13 to 2.89)**	0.70 (-0.39 to 1.79)	0.15 (-0.20 to 0.50)
	Adjusted ‡	1.45 (-0.31 to 3.20)	1.06 (-0.28 to 2.40)	0.39 (-0.75 to 1.52)	0.10 (-0.25 to 0.45)

Values in the table are regression coefficients (with 95% confidence intervals) from linear regression analyses with physical activity (PA) enjoyment (dichotomized over the median) as independent variable and physical activity levels (% time spent per day) as dependent variable, ‡ adjusted for child's age, recruitment group, maternal education, season, child's BMI, and impulsivity. Bold numbers represent statistical significance (*p* <0.05).

In boys, associations between PA enjoyment and PA behavior were stronger with relatively high impulsivity. For example, in boys who scored high on impulsivity, PA enjoyment had a stronger positive relation with percentage of time spent in MVPA than in boys who scored low on impulsivity (regression coefficient 1.30 versus -1.85). This difference is represented by the statistically significant interaction term of 2.84 (0.27 to 5.41). By contrast, in girls, associations between PA enjoyment and PA behavior were stronger with relatively low impulsivity. For example, in girls who scored low on impulsivity, PA enjoyment had a stronger positive relation with percentage of time spent in MVPA than in girls who scored low on impulsivity (regression coefficient -0.83 versus 1.19), respectively. This difference is represented by the interaction term of -2.00 (-4.29 to 0.29).

The average percentage explained variance (R-square) of all models was 20.8% (SD = 0.7%) with a minimum of 6.8% (regarding number of PA bouts in boys with high impulsivity), and a maximum of 31.2% (regarding active behavior in boys and girls with relatively low impulsivity). No major differences in explained variance were found between PA intensities and gender.

Table 3. The moderating influence of impulsivity on the association between physical activity enjoyment and PA behavior for boys and girls.

		% Active	% Light	% MVPA	# PA Bouts
Boys	High impulsivity	**3.55 (0.13 to 6.96)**	**2.24 (0.08 to 4.41)**	1.30 (-0.81 to 3.41)	0.14 (-0.38 to 0.67)
	Low impulsivity	-2.18 (-5.27 to 0.91)	-0.34 (-2.48 to 1.81)	-1.85 (-3.69 to 0.00)	**-0.59 (-1.12 to -0.07)**
	Interaction	**5.57 (1.34 to 9.79)**	2.73 (-0.09 to 5.54)	**2.84 (0.27 to 5.41)**	**0.70 (0.03 to 1.38)**
Girls	High impulsivity	-0.23 (-3.16 to 2.70)	0.60 (-1.60 to 2.81)	-0.83 (-2.30 to 0.64)	-0.19 (-0.68 to 0.29)
	Low impulsivity	**2.57 (0.04 to 5.09)**	1.38 (-0.60 to 3.35)	1.19 (-0.78 to 3.17)	0.26 (-0.32 to 0.84)
	Interaction	-2.67 (-6.22 to 0.88)	-0.67 (-3.41 to 2.07)	-2.00 (-4.29 to 0.29)	-0.52 (-1.22 to 0.19)

Note: Linear regression analyses presenting beta's (95% confidence intervals) adjusted for child's age, recruitment group, maternal education, season, child's and BMI. Bold numbers represent statistical significance at p <0.05.

Discussion

The present study showed that impulsivity moderates the relationship between PA enjoyment and PA behavior, but that this moderation is in opposite direction for boys and girls (see Figure 2). In boys, impulsivity strengthened the positive relationship between PA enjoyment and PA behavior while in highly impulsive girls, the relationship between PA enjoyment and PA behavior was absent.

After stratification for gender and impulsivity, we found that relatively PA enjoyment was significantly associated with active behavior (i.e. all PA intensities combined) and not with light PA and MVPA. Other studies have investigated the relationship between PA enjoyment and PA behavior in children. According to the study of Dishman (2005), PA enjoyment resulted in higher PA behavior over one year, by an indirect mediated effect on self-efficacy. One study that – like our study- used the PACES and accelerometry also found no consistent association between PA enjoyment and objectively measured PA behavior, and also suggested that the association between PA enjoyment and PA behavior may be different between boys and girls (3). Wenthe et al. (2009) attempted to explain the lack of empirical support for the relationship between PA enjoyment and PA behavior by methodological imperfection regarding negatively worded questions of the PACES, the lack of within group variance of the PACES, or that PA enjoyment may have acted as a mediator in their study (3).

This study adds to the current literature indicating that impulsivity attenuates the relationship between PA enjoyment and PA behavior in girls. In line with our hypothesis, this can be explained by the nature of impulsive behavior itself; since performance of leisure time PA occurs relatively automatically in impulsive children (40), and thus relatively independent of intrapersonal motives such as PA enjoyment. In girls with relatively low impulsivity on the other hand, leisure time PA occurs more deliberately and is thus more likely to be regulated by personal motives such as PA enjoyment. This is supported by studies that demonstrated impulsivity to be a key moderating factor of influences on child snacking behavior (22,23). In boys by contrast, we found that impulsivity strengthened the relationship between PA enjoyment and PA behavior. As we hypothesized that impulsivity would attenuate the relationship between PA enjoyment and PA behavior, findings in boys are contra-intuitive. One can however cautiously speculate that predominantly in boys, impulsivity may be likely to be associated with hyperactivity (41-43). Impulsivity (and thus hyperactivity) may strengthen the relationship between PA enjoyment and PA behavior in boys as 1) hyperactive boys may be deliberately provided with more PA opportunities by their parents (e.g. membership of sports clubs), thus positively reinforcing impulsive boys' PA enjoyment. In this way, one may cautiously suggest that hyperactive boys may engage in PA more than their non-hyperactive peers, and also score relatively high on the enjoyment of these behaviors. Future studies with a longitudinal design are however warranted. In addition, future studies should incorporate a larger sample allowing for more flexible analytical strategies such as structural equation models in order to analyze various direct, moderating mechanisms simultaneously.

Strengths and weaknesses

In the usage of accelerometers, considerable differences exist in thresholds of defining PA intensity in children. In the present study, we used the thresholds of Evenson because of the similarity of the age of our children compared with those of Evenson's study, and the diverse content of the testing protocol (e.g. free-play activities) (32). In these thresholds, counts above 100 counts per minute were already considered as light PA. As these thresholds were notably lower compared to other thresholds (32), our results may have overestimated the percentage of light PA in children, and underestimated the percentage of sedentary behavior. In this study, sedentary time is defined as any waking time where the accelerometer registered less than 100 counts per minute (often with a sitting or reclining posture) (32). In addition, one may suggest that differences exist between the two Actigraph accelerometer models (i.e. uniaxial ActiGraph 7164 and GT1M) used in our study. The question relevant to the present study is if these differences are large enough to have implications for activity intensity classification. Three studies showed that this was not the case in time spent in the moderate or vigorous category. If one did suppose that differences existed, then this potential bias would be randomly distributed over the entire sample, as we were unaware of any child characteristics when handing out the accelerometers. It is however questionable whether this potential misclassification affected our results, as information from parent diaries showed that 100 children (58,4%) had not swum during the accelerometry measurement. From the 71 children that did

swim, the average duration per day was 17.67 minutes (SD = 13.84). One may argue that seasonality influenced our results as a random error in the measurement of PA behavior. In the present study, 82.5% of the children were measured in spring or summer, and 17.5% in autumn. We tested the interaction of season (i.e. winter, autumn, spring and summer) in the relationship between association between PA enjoyment and PA behavior, and we found no statistically significant interaction. In total, 8.2% of the children in our sample had an alternative lifestyle. As these children may be exposed to alternative lifestyle patterns, the relationship between PA enjoyment and PA behavior may be different in these children. However, we found no evidence for a statistically significant interaction in this relationship.
In the mean score and threshold for the median-split regarding PA enjoyment (see Table 1), one can see that this variable was negatively skewed. Therefore, dichotomy represented a limited contrast between children with normal/high- versus very high PA enjoyment. However, this study showed that even this small contrast was associated with impulsivity, gender differences, and ultimately PA behavior.

Implications

This study shows that a three-way interaction exists regarding PA enjoyment, impulsivity and gender in the relationship with PA behavior. As our limited sample size may have not resulted in statistical significance in all subgroups and all PA intensities, the strength of the regression coefficients in the present study may encourage researchers to investigate these interactions in future studies. Future studies are therefore stimulated to replicate the present study, using a larger sample with more variability in PA enjoyment.

This is the first study that demonstrated moderating influences within the PA enjoyment – objective PA behavior relationship. Future interventions in public health practice should acknowledge that the cross-sectional relationship between PA enjoyment and objectively measured PA behavior remains uncertain and that gender and impulsivity may moderate this relationship. Based on the available evidence to date, the direct relationship between PA enjoyment and PA behavior remains questionable and not straightforward. The extent to which this stems from environmental constraints to perform PA, parental constraints or child personality constraints remains uncertain. This study however indicated that a personality trait (i.e. impulsivity) may play a role in this. Researchers are encouraged to replicate this study using a longitudinal design and focusing on potential moderating factors in this relationship.

Acknowledgments

We would like to thank the children and parents that participated in this part of the KOALA Birth Cohort Study. In addition, we would like to thank Lily Bogaards for her work on the Dutch translation and validation of the PACES. The present study was partially funded by the Netherlands Heart Foundation, grant number 2008 B112 to E.F.C. Sleddens. The authors declare that they have no competing interests.

References

1. Dietz WH. Health Consequences of Obesity in Youth: Childhood Predictors of Adult Disease. Pediatrics. 1998;101(2):518-25.
2. Hagger MS, Chatzisarantis NLD. Intrinsic motivation and self-determination in exercise and sport. Champaign, IL US: Human Kinetics; 2007.
3. Wenthe PJ, Janz KF, Levy SM. Gender similarities and differences in factors associated with adolescent moderate-vigorous physical activity. Pediatric Exercise Science. 2009;21(3):291-304.
4. DiLorenzo TM, Stucky-Ropp RC, Vander Wal JS, Gotham HJ. Determinants of Exercise among Children. II. A Longitudinal Analysis. Preventive Medicine. 1998;27(3):470-7.
5. Lawman HG, Wilson DK, Van Horn ML, Resnicow K, Kitzman-Ulrich H. The relationship between psychosocial correlates and physical activity in underserved adolescent boys and girls in the ACT trial. Journal of Physical Activity and Health. 2011;8(2):253-261.
6. Zhang T. Relations among school students' self-determined motivation, perceived enjoyment, effort, and physical activity behaviors. Perceptual Motor Skills. 2009;109(3):783-90.
7. Dishman RK, Motl RW, Saunders R, Felton G, Ward DS, Dowda M, et al. Enjoyment mediates effects of a school-based physical-activity intervention. Medicine & Science in Sports & Exercise. 2005;37(3):478-87.
8. Moore JB, Yin Z, Hanes J, Duda J, Gutin B, Barbeau P. Measuring Enjoyment of Physical Activity in Children: Validation of the Physical Activity Enjoyment Scale. Journal of Applied Sport Psychology. 2009;21:116-29.
9. Trost SG. State of the art reviews: measurement of physical activity in children and adolescents. American Journal of Lifestyle Medicine. 2007;1(4):299-314.
10. Goran MI, Gower BA, Nagy TR, Johnson RK. Developmental changes in energy expenditure and physical activity in children: evidence for a decline in physical activity in girls before puberty. Pediatrics. 1998;101(5):887-91.
11. Kremers SP, De Bruijn G-J, Visscher TL, Van Mechelen W, De Vries NK, Brug J. Environmental influences on energy balance-related behaviors: a dual-process view. International Journal of Behavioral Nutrition and Physical Activity. 2006;3(1):9.
12. Spence JC, Lee RE. Toward a comprehensive model of physical activity. Psychology of Sport and Exercise. 2003;4(1):7-24.
13. Trost SG, Pate RR, Sallis JF, Freedson PS, Taylor WC, Dowda M, et al. Age and gender differences in objectively measured physical activity in youth. Medicine & Science in Sports & Exercise. 2002;34(2):350-5.
14. Remmers T, Sleddens EF, Gubbels JS, de Vries SI, Mommers M, Penders J, et al. Relationship Between Physical Activity and the Development of BMI in Children. Medicine & Science in Sports & Exercise. 2013;46(1):177-84.

15. Frömel K, Formánková S, Sallis JF. Physical activity and sport preferences of 10 to 14 year old children: A 5 year prospective study. Acta Universitatis Palackianae Olomucensis. Gymnica. 2002;32(1):11-6.
16. Nader PR, Bradley RH, Houts RM, McRitchie SL, O'Brien M. Moderate-to-vigorous physical activity from ages 9 to 15 years. Journal of the American Medical Assocation. 2008;300(3):295-305.
17. Wankel LM. The importance of enjoyment to adherence and psychological benefits from physical activity. International Journal of Sport Psychology. 1993.
18. Faith MS, Leone MA, Ayers TS, Heo M, Pietrobelli A. Weight criticism during physical activity, coping skills, and reported physical activity in children. Pediatrics. 2002;110(2):23.
19. Pikora T, Giles-Corti B, Bull F, Jamrozik K, Donovan R. Developing a framework for assessment of the environmental determinants of walking and cycling. Social Science & Medicine. 2003;56(8):1693-703.
20. Bargh JA, Chartrand TL. The unbearable automaticity of being. American Psychologist. 1999;54(7):462.
21. Aarts H, Paulussen T, Schaalma H. Physical exercise habit: on the conceptualization and formation of habitual health behaviours. Health Education Research. September 1, 1997 1997;12(3):363-74.
22. Guerrieri R, Nederkoorn C, Jansen A. The interaction between impulsivity and a varied food environment: its influence on food intake and overweight. International Journal of Obesity. 2007;32(4):708-14.
23. Nederkoorn C, Braet C, Van Eijs Y, Tanghe A, Jansen A. Why obese children cannot resist food: the role of impulsivity. Eating behaviors. 2006;7(4):315-22.
24. Donnelly JE, Jacobsen DJ, Whatley JE, Hill JO, Swift LL, Cherrington A, et al. Nutrition and Physical Activity Program to Attenuate Obesity and Promote Physical and Metabolic Fitness in Elementary School Children. Obesity Research. 1996;4(3):229-43.
25. Kummeling I, Thijs C, Penders J, Snijders BE, Stelma F, Reimerink J, et al. Etiology of atopy in infancy: The KOALA Birth Cohort Study. Pediatric Allergy and Immunology. 2005;16(8):679-84.
26. Cremers E, Thijs C, Penders J, Jansen E, Mommers M. Maternal and child's vitamin D supplement use and vitamin D level in relation to childhood lung function: the KOALA Birth Cohort Study. Thorax. 2011;66(6):474-80.
27. Eijkemans M, Mommers M, de Vries SI, van Buuren S, Stafleu A, Bakker I, et al. Asthmatic symptoms, physical activity, and overweight in young children: a cohort study. Pediatrics. Mar 2008;121(3):666-72.
28. Kendzierski D, DeCarlo KJ. Physical Activity Enjoyment Scale: Two validation studies. Journal of Sport & Exercise Psychology. 1991;13(1).
29. Motl RW, Dishman RK, Saunders R, Dowda M, Felton G, Pate RR. Measuring enjoyment of physical activity in adolescent girls. American Journal of Preventive Medicine. 2001;21(2):110-7.

30. Bogaards L, Thijs C, Sleddens E, Kremers SP. Measuring behavioural regulation of physical activity in children: Development and validation of a questionnaire. Manuscript submitted for publication. 2014.
31. Nunnally JC, Bernstein IH. Psychometric theory. 1994. McGraw, New York. 1991.
32. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. Journal of Sports Sciences. 2006;24(14):1557-65.
33. Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth: a review. American Journal of Preventive Medicine. 2011;41(4):442-55.
34. Solanto M, Abikoff H, Sonuga-Barke E, Schachar, R, Logon GD, Wigal T, et al. The Ecological Validity of Delay Aversion and Response Inhibition as Measures of Impulsivity in AD/HD: A Supplement to the NIMH Multimodal Treatment Study of AD/HD. Journal of Abnormal Child Psychology. 2001;29(3):215-28.
35. Simonds J, Rothbart MK. The Temperament in Middle Childhood Questionnaire (TMCQ): A computerized self-report instrument for ages 7–10. Paper presented at: Poster presented at the Occasional Temperament Conference, Athens, 2004.
36. Sleddens EF, Kremers SP, De Vries NK, Thijs C. Measuring child temperament: Validation of a 3-item Temperament Measure and 13-item Impulsivity Scale. European Journal of Developmental Psychology. 2013;10(3):392-401.
37. Rothbart MK, Ahadi SA, Hershey KL, Fisher P. Investigations of temperament at three to seven years: The Children's Behavior Questionnaire. Child Development. 2001;72(5):1394-1408.
38. Fredriks AM, van Buuren S, Wit JM, Verloove-Vanhorick S. Body index measurements in 1996–7 compared with 1980. Archives of Disease in Childhood. 2000;82(2):107-12.
39. Trost SG, Pate RR, Sallis JF, Freedson PS, Taylor WC, Dowda M, et al. Age and gender differences in objectively measured physical activity in youth. Medicine & Science in Sports & Exercise. 2002;34(2):350-5.
40. Zaparniuk J, Taylor S. Impulsivity in children and adolescents. In: Jackson CDWMA. Impulsivity: Theory, assessment, and treatment. New York, NY, US: Guilford Press; 1997:158-179.
41. Messer SB. Reflection-impulsivity: A review. Psychological Bulletin. 1976;83(6):1026-1052.
42. Dellu-Hagedorn F. Relationship between impulsivity, hyperactivity and working memory: a differential analysis in the rat. Behavioral and Brain Functions. 2006;2(10).
43. Gaub M, Carlson CL. Gender Differences in ADHD: A Meta-Analysis and Critical Review. Journal of the American Academy of Child and Adolescent Psychiatry. 1997;36(8):1036-45.

CHAPTER 4

A longitudinal study of children's outside play using family environment and perceived physical environment as predictors

This chapter has been published as:

Remmers T, Broeren SM, Renders CM, Hirasing RA, van Grieken A, Raat H. A longitudinal study of children's outside play using family environment and perceived physical environment as predictors. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1):76.

Abstract

Background: A natural and cheap way of increasing children's physical activity is stimulating unstructured outside play.
Purpose: This study examined whether characteristics of the family and perceived physical environment were associated with the duration of children's outside play.
Methods: Parents participating in the "Be Active, Eat Right" cluster RCT control group (N = 2007) provided information on potential predictors of outside play (i.e. family and perceived physical environment) of their 5-year-old child by questionnaire. Child outside play was assessed by parental reports both at five and seven years. Linear regression analyses, adjusted for seasonality, were performed to evaluate associations between potential predictors and child outside play. Linear mixed models were fitted to evaluate the relationship between potential predictors and the development of outside play over two years, with season entered as a random factor.
Results: Family environment was the strongest construct predicting child outside play, while parent perceived physical environment had no significant association with child outside play. Parental habit strength and the presence of rules were the strongest predictors of increased outside play. Parent perceived difficulty in improving child outside play was the strongest predictor of decreased outside play.
Conclusion: Family environment predicted child outside play and not perceived physical environment. Parental rules and habit strength regarding improving outside play were associated with an improvement of child's engagement in outside play.

Background

A natural and cheap way of increasing children's physical activity (PA) is by stimulation of outside play, defined as play behavior without any given tasks or goals; unstructured free play. Child outside play (OP), as a specific type of PA behavior, has been shown to increase a child's total PA level (1, 2) and children who spent more time outdoors were shown to be more active than children who spent less time outdoors (3, 4, 5). Recommendations from an expert committee on the prevention of childhood obesity acknowledge unstructured play as most appropriate to increase PA in young children (6). OP is also positively associated with children's social skills as they learn to account for other children (7, 8, 9) and provides children with opportunities to acquire new motor skills such as climbing, jumping, hanging and sliding in a self-regulatory way (10). Studies have shown that relatively minor adjustments to school playgrounds lead to increases in PA, which makes OP relatively modifiable (11). In order to enable effective increasing of child's engagement in this promising type of PA behavior, determinants of this behavior should be assessed.

Previous studies mainly focused on determinants of PA in general. These studies found that gender (i.e. male), child's PA enjoyment, and summer and spring season were consistently related with higher levels of PA in children (12). There may be specific determinants for OP as a specific type of children's PA behavior, however studies focusing on determinants of OP specifically are scarce. Currently, two studies have specifically examined determinants of OP, also investigating attributes of the physical environment (PE). A cross-sectional study reported that lower parental education and the importance parents ascribe to OP were associated with more OP in 4- to 12-year-old children (13). A longitudinal study reported that children's outdoor tendencies and parental encouragement were related to increases in OP across a time span of five years (14). Both studies indicate that family environment may play an important role in child's duration of OP.

Studies that incorporate a longitudinal design and use a broader range of environmental variables (e.g. parent perceived safety) to identify determinants of OP are warranted (14). Therefore, the present study examined whether the family environment and perceived PE are associated with the duration of children's OP behavior, acknowledging the potential role of gender and seasonal variety and using a broad range of variables covering both the family environment and perceived PE.

Methods

Study design and population

The present study was embedded in the "Be Active, Eat Right" study, a cluster RCT investigating the effect of an overweight prevention protocol described in detail elsewhere (9). The Medical Ethics Committee of the Erasmus University Rotterdam

Medical Center approved the study protocol (reference number MEC-2007-163). All parents provided written informed consent.

This study used a longitudinal design to evaluate determinants of OP development over time. We limited our sample to participants that were allocated to youth healthcare teams participating in the control condition. In the control condition, all parents (N = 3,942) were requested to fill in and return a baseline questionnaire at enrollment (child age five), which assessed socio-demographic characteristics, family environment and parent-perceived PE and the duration of OP (2007–2010). Specific variables of family environment were based on established theories, such as social cognitive theory (e.g. self-efficacy) (15), theory of planned behavior (e.g. intention, attitudes) (16), and social leaning theory (e.g. modeling of spouses and parents) (17). Variables of perceived PE were based on promising results of earlier studies evaluating the influence of the environment on children's health behavior (e.g. presence of sidewalks, parent perceived safety) (18).

At age seven, duration of OP was assessed again by questionnaire. Records with missing data on the outcomes of interest (i.e. OP at age five and seven, n = 1,895) were excluded from the analyses. By doing so, the population for analysis consisted of N = 2,007 parents and children.

Measurements

Socio-demographic characteristics

The child's gender, age (in years) and ethnic background were assessed. Child's ethnic background was considered to be "non-Dutch" when at least one of the parents was born abroad, as defined by Statistics Netherlands. Height and weight of the child were measured at age five by healthcare professionals using standardized protocols (19).Respondents were either the father or the mother of the child, and parental gender was entered as a potential confounder in subsequent analyses. From this point onwards, respondent will be described as "parent." Parental age and parental education (low, mid-low, mid-high, high) were assessed in the baseline questionnaire (20).

Family environment and physical environment

A full description of constructs, construct properties, items and response scales is presented in Appendix 1.

Child outside play

OP was defined by the total duration of unstructured OP of the child in an average week. Note that this is without organized sports, school PE and/or active transport. At both baseline (child age five) and two-year follow-up (child age seven), OP was assessed using an identical set of questions. Total duration of OP was therefore computed in a similar way for both time points, as presented below.

First, parents were asked how many weekdays and weekend days in an average week their child played outside. Second, parents were asked to indicate the average duration in the morning, noon and evening that their child played outside, again separately for weekdays and weekend days. We computed total minutes of OP in the morning, noon and evening. Responses were multiplied by the indicated number of days that the child played outside, separately for weekdays and weekend days. Finally, we summed weekdays and weekend days in order to arrive at the average minutes of OP. We used the date on which the questionnaire was completed to classify the season (i.e. winter, spring, summer and autumn) of both OP at age five and seven. Season was then used as a confounder in all subsequent analyses.

Statistical analysis

Characteristics of the population for analysis at child age five were evaluated with descriptive statistics. As PA levels have shown to considerably differ between boys and girls (21), we explored this potential gender difference with chi-square tests and t-tests for categorical and continuous levels of measurements, respectively. Based on the results described in Table 1, we decided not to stratify our subsequent analyses for child gender, as no significant differences were found for the predictors.

We fitted general linear regression models with predictors at child age five as independent variables and OP of the child at age five as the dependent variable. First, we tested univariate associations between each predictor and OP. Relevant predictors ($p < 0.10$) were entered in separate models per category of predictors, namely socio-demographic characteristics (Model 1), family environment (Model 2) and perceived PE (Model 3). In Model 4, all predictors were entered simultaneously. In all models, season at child age five was added as a confounder.

We fitted linear regression models between OP at age seven as the dependent variable and selected predictors at child age five as independent variables. Season at age seven was entered as a confounder. All variables were selected and further entered in the model in a similar way as described for the cross-sectional analyses.

Linear mixed models were used to evaluate the influence of the family and perceived PE on the development of OP over two years. We entered OP at five and seven (additional row for a repeated observation), with season at age five and seven entered as a random effect. To investigate the influence of predictors on the development of OP (i.e. change over time) we computed time in years to follow-up by subtracting child age at follow-up from child age at baseline. Subsequently, we modelled interactions between “time to follow-up” and individual predictors to evaluate whether there were associations between the predictor and OP development between child age five and seven. We again selected these predictors based on univariate associations.

Drop-out analyses were performed by means of t-tests for continuous socio-demographic variables (child age, child BMI and parental BMI) and chi-square tests for categorical variables (child gender, child ethnic background, parental ethnic background and parental educational level). All analyses were performed with SPSS version 20.0 (IBM Corp., NY, USA). Multi-collinearity seemed to be a minor issue, as all individual predictors showed variance inflation factors of < 10 (22).

Results

Baseline characteristics

Table 1 shows the characteristics of the study population at baseline. Of the children, 50.5% were boys and 49.5% were girls. Children were predominantly of Dutch ethnic background (91.1%). Boys were older than girls and engaged in more minutes of OP than girls. In total, 76.3% of the children engaged in 60 or more minutes of OP per day (i.e. met the WHO guideline of PA). Respondents were predominantly mothers (91.0%), and 95.2% were of Dutch ethnic background. Regarding family environment of the participating children, only 11.3% perceived improving their OP as difficult. Regarding perceived PE, parents of boys perceived more safety in the evening compared to parents of girls.

Compared to children with missing data, the population for analysis consisted of a higher percentage of children with a Dutch ethnic background, a higher percentage of parents with a Dutch ethnic background and a higher percentage of high education parents (all $p < 0.05$). This means that relatively lower educated parents were more likely to have one or more missing values on their OP.

Table 1: Baseline characteristics at child age five years

	Total (n =2007)	Boys (n =1013)	Girls (n = 994)
Child socio-demographics			
Age at baseline; mean years (sd) (missing n = 6)	5.75 (0.42)	5.77 (0.42)	5.72 (0.41)
Ethnic background; n Dutch (%) (missing n = 27)	1804 (91.10)	996 (98.61)	974 (98.38)
BMI; mean kg/m2 (sd) (missing n = 6)	15.39 (1.47)	15.42 (1.35)	15.36 (1.59)
Average minutes of outside play; mean (sd) (missing n =0)	108.99 (65.01)	112.72 (65.86)	104.72 (63.41)
Outside play ≥ 60 minutes per day, n (%) (missing =0)	76.3	78.9	73.6

Parental socio-demographics			
Age; mean years (sd), in years (missing n = 6)	37.14 (4.38)	37.07 (4.37)	37.21 (4.40)
Gender; n male (%) (missing n = 7)	179 (9.00)	94 (9.31)	85 (8.59)
Ethnic background; n Dutch (%) (missing n = 1)	1909 (95.20)	996 (97.67)	943 (96.38)
Education level; n (%) (missing n = 1)			
Low	50 (2.50)	23 (2.27)	27 (2.72)
Mid-low	288 (14.40)	142 (14.03)	146 (14.69)
Mid-high	902 (45.00)	463 (45.75)	439 (44.16)
High	766 (38.20)	384 (37.94)	382 (38.43)
BMI; mean kg/m2 (sd) (missing n = 32)	23.94 (7.98)	24.11 (10.65)	23.77 (3.60)
Family environment			
Parental attitude; meanscore (sd) (missing n = 16)	3.61 (1.05)	3.60 (1.06)	3.62 (1.04)
Family attitude; meanscore (sd) (missing n = 42)	2.76 (1.04)	2.73 (1.04)	2.79 (1.04)
Self-confidence; n agree (%) (missing n = 86)	1021 (53.10)	529 (54.37)	492 (51.90)
Perceived difficulty; n agree (%) (missing n = 53)	220 (11.30)	107 (10.81)	113 (11.72)
Habit strength; n agree (%) (missing n = 30)	1607 (81.30)	836 (83.52)	771 (79.00)
Intention to improve; n agree (%) (missing n = 51)	881 (45.00)	438 (44.20)	443 (45.91)
Monitoring; n frequent (%) (missing n = 7)	1565 (78.30)	794 (78.69)	711 (77.80)
Active encouragement; n frequent (%) (missing n = 12)	1639 (82.60)	822 (82.28)	817 (82.86)
Child autonomy; n frequent (%) (missing n = 18)	421 (21.10)	215 (21.39)	206 (20.81)
Perception of outside play; n more (%) (missing n = 42)	539 (27.40)	295 (29.65)	244 (25.15)
Presence of rules; % with rules (missing n = 118)	814 (43.10)	425 (44.69)	389 (41.47)
Modelling parent, mean days PA (sd) (missing n = 169)	4.49 (2.10)	4.49 (2.12)	4.49 (2.08)
Modelling partner, mean days PA (sd) (missing n = 157)	4.83 (2.27)	4.83 (2.30)	4.81 (2.24)
Modelling siblings, mean days PA (sd) (missing n = 266)	6.58 (1.61)	6.59 (1.62)	6.56 (1.61)

Perceived physical environment			
Traffic business; n agree (%) (missing n = 2)	567 (28.30)	279 (27.57)	288 (29.00)
Safety perception during daytime; n agree (%) (missing n = 11)	1460 (73.10)	751 (74.50)	709 (71.76)
Safety perception during evenings; n agree (%) (missing n = 17)	1035 (52.00)	543 (54.19)	492 (49.80)
Presence of sidewalks; n agree (%) (missing n = 11)	1365 (68.40)	701 (69.47)	664 (67.27)
Friendliness for children; n agree (%) (missing n = 10)	1661 (83.20)	847 (84.11)	814 (82.22)
Attractiveness for children; n agree (%) (missing n = 14)	1502 (75.20)	763 (75.84)	739 (74.50)
Opportunities for outside play; n agree (%) (missing n = 16)	1390 (69.70)	703 (69.81)	687 (69.60)
Safety without supervision; n agree (%) (missing n = 12)	1093 (54.80)	557 (55.42)	537 (54.09)

Chi-square for categorical variables and t-test for continuous variables, Numbers printed in bold represent $p < 0.05$.

Associates of OP at child age five

Table 2 shows the cross-sectional associations between predictors at child age five and OP at child age five. Parental self-confidence, traffic business and the presence of sidewalks in the neighborhood showed a non-significant univariate association with OP ($p > 0.10$) and were therefore not included in the models.

The socio-demographic variables explained 13% of the variance in OP. Two variables were consistently related to OP: child age and child BMI. Specifically, a one-year increment in child's age at baseline was associated with a 13.56-minute increase in OP per day.

Family environment variables explained 27% of the variance in OP at age five. Parents who indicated difficulty towards improving OP reported their child to play outside 16.33 (95% CI = −26.41 to −6.26) minutes less per day. Parents with a habit towards improving OP reported 33.41 (95% CI = 25.05 to 41.77) more minutes of OP. The presence of rules regarding OP was associated with 19.87 (95% CI = 13.44 to 26.30) more minutes of OP. Parents of children that indicated intention to improve their child's OP reported 12.83 (95% CI = −19.73 to −5.92) less minutes of OP. Perceived PE together explained 10% of the variance in OP at age five. No variables within perceived PE were significantly related with OP at child age five.

Table 2: Linear regression models examining factors related to child outside play at age five (min/day)

	Model 1 beta (95% CI)	Model 2 beta (95% CI)	Model 3 beta (95% CI)	Model 4 beta (95% CI)
n	1940	1390	1968	1337
Socio-demographics				
Child age at baseline	14.42 (6.71 to 22.14)			13.61 (5.13 to 22.08)
Child gender; boy	6.52 (1.12 to 11.91)			4.07 (−1.79 to 9.93)
Child ethnic background; Dutch	1.79 (−11.99 to 15.57)			−4.45 (−20.26 to 11.36)
Child BMI	2.11 (0.25 to 3.96)			2.00 (−0.22 to 4.21)
Parental age at baseline	−0.62 (−1.28 to 0.03)			−0.33 (−1.08 to 0.42)
Parental ethnic background; Dutch	22.94 (4.74 to 41.14)			11.34 (−11.12 to 33.80)
Parental BMI	0.26 (−0.08 to 0.60)			1.14 (0.26 to 2.02)
Parental education level				
Low	reference			reference
Mid-low	15.61 (−7.34 to 38.55)			15.64 (−21.27 to 52.56)
Mid-high	7.82 (−14.40 to 30.04)			10.35 (−25.97 to 46.67)
High	−3.90 (−26.26 to 18.46)			−2.04 (−38.45 to 34.37)
Family environment [1]				
Parental attitude (agree)		−4.32 (−8.01 to −0.63)		−3.78 (−7.46 to −0.10)
Family attitude (agree)		−2.30 (−6.15 to 1.55)		−2.41 (−6.27 to 1.46)
Perceived difficulty (agree)		−18.06 (−28.12 to −8.00)		−16.33 (−26.41 to −6.26)
Habit strength (agree)		33.89 (25.52 to 42.75)		33.41 (25.05 to 41.77)
Intention to improve (agree)		−10.81 (−17.64 to −3.98)		−12.83 (−19.73 to −5.92)
Presence of rules		23.98 (17.60 to 30.36)		19.87 (13.44 to 26.30)
Presence of monitoring		4.90 (−2.90 to 12.70)		4.87 (−2.97 to 12.71)
Presence of active encouragement		−5.26 (−12.71 to 2.19)		−3.00 (−10.48 to 4.48)
Child autonomy (agree)		12.16 (3.83 to 20.49)		11.66 (3.30 to 20.02)
Modelling parent (#days physically active)		0.88 (−0.63 to 2.39)		0.58 (−0.95 to 2.10)
Modelling partner (#days physically active)		0.39 (−0.99 to 1.78)		0.84 (−0.58 to 2.25)
Modelling siblings (#days physically active)		5.01 (3.02 to 6.99)		4.82 (2.81 to 6.83)
Perceived physical environment [1]				
Safety perception during daytime (agree)			−0.81 (−9.67 to 8.05)	0.20 (−9.54 to 9.94)
Safety perception during evenings (agree)			11.82 (4.89 to 18.74)	5.21 (−2.15 to 12.58)
Friendliness for children (agree)			4.43 (−6.52 to 15.37)	−2.63 (−14.53 to 9.27)
Attractiveness for children (agree)			0.84 (−9.03 to 10.72)	−2.79 (−13.43 to 7.85)
Safety of outside play without supervision (agree)			1.91 (−4.99 to 8.81)	−0.40 (−7.89 to 7.09)
R-square [2]	0.13	0.27	0.10	0.31

[1]: For details on the measures used see Table S1 (in Appendix 1).

[2]: R square statistic represents the level of variance explained by the general linear model.

Note: numbers printed bold represent a statistically significant ($p < .05$) association between the predictor and child outside play at five years old.

Associates of OP at child age seven

Table 3 shows longitudinal associations between predictors at child age five and OP at child age seven. Child and parental ethnic background, parental BMI, parental self-confidence, traffic business in the neighborhood and the presence of sidewalks in the neighborhood showed a non-significant univariate association with OP ($p > 0.10$) and were therefore not included in the models.

Socio-demographic variables explained 10% of the variance in OP at age seven. Only education was consistently related with OP ($p < 0.05$); parents with high education reported their child to play outside 28.40 minutes less (95% CI = −55.66 to −1.14) compared to parents with low education.

Family environment variables together explained 15% of the variance in OP at age seven. Parents who indicated difficulty towards improving OP reported 22.11 (95% CI = −33.41 to −10.81) less minutes of OP. Parents with a habit towards improving OP reported 23.99 (95% CI = 14.61 to 33.61) more minutes of OP. The presence of rules regarding OP was associated with 16.46 (95% CI = 9.26 to 23.67) more minutes of OP. Parental active encouragement at child age five was associated with 8.91 (95% CI = −17.33 to −0.48) less minutes of OP at child age seven. Perceived PE together explained 6% of the variance in OP at age seven. No variables within perceived PE were significantly related with OP at child age seven.

Table 3: Linear regression models examining factors related to child outside play at age seven (min/day)

	Model 1 beta (95%CI)	Model 2 beta (95%CI)	Model 3 beta (95%CI)	Model 4 beta (95%CI)
n	1994	1390	1968	1363
Socio-demographics				
Child age at baseline	7.98 (0.88 to 15.09)			4.65 (−3.50 to 12.79)
Child gender; boy	8.51 (2.68 to 14.34)			6.36 (−0.20 to 12.93)
Child BMI	1.21 (−0.79 to 3.21)			1.72 (−0.72 to 4.16)
Parental age at baseline	−0.85 (−1.55 to −0.15)			−0.41 (−1.23 to 0.41)
Parental education level				
Low	reference			reference
Mid-low	17.59 (−2.34 to 37.52)			8.87 (−19.62 to 37.35)
Mid-high	−1.73 (−20.66 to 17.20)			−8.25 (−35.67 to 19.17)
High	−19.50 (−38.58 to −0.41)			−26.63 (−54.10 to 0.84)
Family environment [1]				
Parental attitude (agree)		−3.80 (−7.97 to 0.37)		−3.97 (−8.08 to 0.15)
Family attitude (agree)		−3.22 (−7.57 to 1.13)		−2.87 (−7.19 to 1.45)
Perceived difficulty (agree)		−24.44 (−35.81 to −13.06)		−22.11 (−33.41 to −10.81)
Habit strength (agree)		25.19 (15.72 to 34.67)		23.99 (14.61 to 33.36)
Intention to improve (agree)		−1.12 (−8.84 to 6.60)		−2.88 (−10.57 to 4.81)
Presence of rules		21.49 (14.28 to 28.69)		16.46 (9.26 to 23.67)
Presence of monitoring		2.97 (−5.83 to 11.78)		5.30 (−3.42 to 14.02)
Presence of active encouragement		−10.82 (−19.25 to −2.39)		−8.91 (−17.33 to −0.48)
Child autonomy (agree)		5.48 (−3.95 to 14.90)		4.80 (−4.59 to 14.19)
Modelling parent (#days physically active)		0.50 (−1.21 to 2.20)		0.45 (−1.24 to 2.15)
Modelling partner (#days physically active)		1.49 (−0.07 to 3.05)		1.85 (0.27 to 3.42)
Modelling siblings (#days physically active)		1.06 (−1.18 to 3.30)		1.27 (−0.99 to 3.52)
Perceived physical environment [1]				
Safety perception during daytime (agree)			−3.57 (−13.24 to 6.10)	2.88 (−8.03 to 13.79)
Safety perception during evenings (agree)			8.68 (1.18 to 16.19)	3.54 (−4.68 to 11.76)
Friendliness for children (agree)			4.63 (−7.31 to 16.57)	−5.57 (−18.66 to 7.72)
Attractiveness for children (agree)			4.88 (−5.89 to 15.64)	3.21 (−8.62 to 15.05)
Safety of outside play without supervision (agree)			3.93 (−3.57 to 11.43)	0.12 (−8.22 to 8.47)
R-square [2]	0.10	0.15	0.06	0.20

[1]: For details on the measures used see Table S1 in Appendix 1.

[2]: R square statistic represents the level of variance explained by the general linear model.

Note: numbers printed bold represent a statistically significant ($p < .05$) association between the predictor and child outside play at five years old.

Associates of OP development between child age five and seven

Child age, child and parental ethnic background, parental attitude, family attitude, intention to improve, the presence of rules and positive modelling of siblings were included in the models, presented in Table 4, as these variables showed significant univariate associations (i.e. $p > 0.10$). This means that none of the variables within perceived PE were related to OP (i.e. change between child age five and seven).

Regarding socio-demographic variables, child age at baseline was related to a significant change in OP between baseline and follow-up (Table 4; $p < 0.05$). This was possible as all children were not precisely five years old at baseline. This means that a higher child age was related to higher engagement in OP at baseline, but that this attenuated significantly over time.

Regarding family environment, the intention to improve OP and the presence of rules were both associated with a decrease of OP over time compared to baseline (i.e. Table 2). This means that modelling of sibling was related to higher engagement in OP at baseline, but that this attenuated significantly over time.

Table 4: Linear mixed models examining factors related to child outside play development between age five and seven (min/day)

n =1552	Adjusted effect* at baseline	Adjusted effect* at 2 years follow-up	p for time interaction
Socio-demographics			
Child age at baseline	26.17 (19.19 to 33.14)	5.71 (−2.57 to 13.99)	< 0.01
Child ethnic background; Dutch	−3.03 (−18.47 to 12.40)	−1.22 (−18.73 to 16.28)	0.86
Parental ethnic background; Dutch	21.28 (0.56 to 42.00)	8.19 (−15.79 to 32.17)	0.36
Family environment [1]			
Parental attitude (agree)	−5.83 (−9.32 to −2.34)	−5.74 (−9.95 to −1.52)	0.97
Family attitude (agree)	−5.07 (−8.67 to −1.47)	−3.59 (−7.88 to 0.70)	0.56
Intention to improve (agree)	−11.33 (−18.01 to −4.66)	−4.34 (−12.15 to 3.46)	0.14
Presence of rules	29.71 (23.89 to 35.54)	23.85 (17.04 to 30.66)	0.15
Modelling siblings (# days physically active)	7.56 (5.76 to 9.36)	3.95 (1.87 to 6.03)	< 0.01

[1]: For details on the measures used see Table S1 in Appendix 1. *Adjusted for season, age at baseline and follow-up. Adjusted effects are not exactly equal to results in Tables 2 and 3 because of differences in included covariates, and model specifications. Note: numbers printed bold represent statistically significant associations between the predictor and child outside play.

Discussion

This study has shown that family environment was the strongest construct of variables predicting OP, compared to socio-demographic characteristics and perceived PE. More specifically, this study has demonstrated that habit strength and the presence of rules were positive, strong and stable predictors of OP over time. Positive modelling by siblings and child age at baseline were also positive predictors. In contrast, parent perceived difficulty in improving OP was a negative (i.e. related to less minutes of OP), relatively strong and stable predictor of OP over time.

As this study focused on unstructured OP, results are not generalizable to organized sports, school PE and/or active transport PA. Therefore, one should be cautious in directly relating an increase in OP with more PA energy expenditure (PAEE) and the accompanied benefits regarding childhood obesity. However, considering the various benefits of OP (e.g. increased PA, motor abilities and social skills), it may contribute to an improved general health status of the child over time.

This study has found no relationship between perceived PE and OP, which is in line with a cross-sectional study among 4- to 12-year-old children (13) and a longitudinal study among 5- to 6-year-old children (14). Hypothetically, an explanation for this may be that parents have other perceptions regarding PA opportunities in their neighborhood than their children, which may also explain the relatively weak associations regarding attractiveness, child friendliness and traffic busyness. Therefore, future studies are urged to assess both parental and children’s motives for OP. Another explanation may be that attributes of perceived PE are moderated or mediated by family environment. Future studies are encouraged to investigate these mechanisms.

Our study has found that a positive parental attitude and family attitude were related to less time spent on OP. An explanation for this contra-intuitive finding may be that some parents in the present study perceived that their child needed more PA or OP and these parents had the intention to improve but were unable to achieve this yet compared to other children (23). Another explanation may be that reverse causation played a role here, as parents may consider their OP as sufficient and therefore did not think their child could/should improve on this. In addition, active parental encouragement towards improving OP was related to less OP over time, which may be explained by the possibility that active encouragement conflicts with the self-regulatory character of OP. It may be suggested that facilitation and providing autonomy may be more effective in promoting OP in children.

Our positive association regarding parental rules and duration of OP were not in line with the findings of Sallis et al. (22). Discrepancy in the formulation of rules may explain this as Sallis et al. formulated rules merely related to the discouragement of OP (e.g. do not play rough games), while this study solely asked for the presence of rules regarding OP.

This study has demonstrated a negative association between parent-perceived difficulty in improving their child's OP and OP at child age five and seven. This indicates that parents are able to indicate difficulties, and that the presence of these difficulties was indeed associated with relatively low levels of OP. Future studies should investigate these difficulties more thoroughly to identify what the exact difficulties are that parents are struggling with (e.g. time constraints, child's friends to play with, etc.).

Strengths and weaknesses

A strength of the present study is its longitudinal design, including a relatively large sample. In addition, this study assessed PA through a whole year, subsequently adjusting for the effect of seasonality. The present study's selective analytical approach resulted in sufficient model stability. This can be seen in the stability of parameters across model-variations (e.g. stability of parental age between models 1 and 4 of Table 2) and the relatively large sample size. In addition, multi-collinearity seemed to be a minor issue, as all individual predictors showed variance inflation factors of < 10 (24).

Our drop-out analyses showed that relatively lower educated parents were more likely to have one or more missing values on their OP. This may be due to misunderstanding the Dutch translation of "OP" or the relative complexity of the question assessing OP. In addition, as we are aware that in some of our cross-sectional results reversed causation may have played a role, we urge future studies to use longitudinal designs in order to unravel this, especially regarding the relationship between parental and family attitude and OP.

To date, OP can only be assessed by parental report, as often-used single objective measurements (e.g. accelerometers or heart-rate monitors) cannot distinguish OP from other types of PA. However, future studies need to assess OP using objective measures. In this regard, special attention should be directed towards combining global positioning system (GPS), GIS, and accelerometers, whose methodologies yield an objective assessment of domain-specific PA (25, 26).

The present study used parental perception of their PE while nowadays more detailed objective assessment of the environment is also available: for example, with the use of geographic information systems (GIS) (27). Studies that directly compared objective and perceived PE suggest that these two concepts are different but interrelated (18, 28, 29). Although studies using perceived physical environment have shown relatively weak associations with objective PA (30, 31), consistency was higher when PA was also measured by parental reports (18). This is supported by several conceptual frameworks, which postulate that perceived PE may be a more proximal function of the objective environment (28, 29), as the influence of objective PE is moderated by personal factors and selective daily mobility (32, 33). Therefore, future studies need to include both objective and subjective measures of PE to unravel these phenomena.

Regarding the relative contribution of OP to total PA, only one study estimated the proportion of moderately to vigorously intense PA (MVPA) during OP in special playgrounds adapted to promote PA, and reported that approximately 35% of the time spent in OP was MVPA (34). Future studies are therefore also encouraged to quantify the contribution of OP to total physical activity energy expenditure. Irrespective of the intensity of OP, approximately 76% of the children engaged in ≥ 60 minutes of OP. As this may be higher than other studies, the present results may be limited in their generalizability.

Conclusion

Although other studies reported that the attributes of perceived PE are associated with a child's PA behavior, this study has revealed that family environment overpowers these attributes of perceived PE at child age five and seven. This means that a supportive family environment is the key determinant of regular OP. Future studies are encouraged to investigate the potential moderating role of family environment in the relationship between perceived PE and OP.

More specifically, this study has demonstrated that the presence of parental rules and parental habit strength was associated with more OP, and perceived difficulty was associated with less OP. As these relationships were stable over two years, future interventions to increase OP should parents to set clear rules about OP and subsequently foster habit formation regarding OP. Future studies should also implement qualitative methods to investigate reasons behind, among others, the parental perception of difficulty to improve OP. These studies may provide interesting insights for the development of evidence-based intervention programs supporting parents to promote OP.

Acknowledgements

This study is funded by a grant from the major funding body ZonMW, the Netherlands Organization for Health Research and Development (project no. 50–501 10–98). All authors declare that they have no competing interests.

Competing interests

All authors declare that they have no competing interests.

Authors' contributions

HR, RH, and CR originated the idea for the study and its design and were responsible for acquiring the grant for the study. AG acquired the data. TR drafted the manuscript and performed the statistical analyses. SB and AG critically reviewed the statistical analyses and interpretation. All authors critically read and approved the final manuscript.

References

1 Brown WH, Pfeiffer KA, McIver KL, Dowda M, Addy CL, Pate RR. Social and environmental factors associated with preschoolers' nonsedentary physical activity. Child Development. 2009;80:45-58.

2 Wickel EE, Eisenmann JC. Contribution of youth sport to total daily physical activity among 6-to 12-yr-old boys. Medicine & Science in Sports & Exercise. 2007;39:1493-1500.

3 Hinkley T, Crawford D, Salmon J, Okely AD, Hesketh K. Preschool children and physical activity: a review of correlates. American Journal of Preventive Medicine. 2008;34(5):435-41.

4 Mackett RL, Lucas L, Paskins J, Turbin J, The therapeutic value of children's everyday travel. Transportation Research. 2005;39(2):205-19.

5 Page A, Cooper A, Griew P, Davis L, Hillsdon M. Independent mobility in relation to weekday and weekend physical activity in children aged 10–11 years: the PEACH project. International Journal of Behavioral Nutrition and Physical Activity. 2009;6(1):2.

6 Barlow SE, Dietz WH. Obesity evaluation and treatment: expert committee recommendations. Pediatrics. 1998;102(3):29.

7 Burdette HL, Whitaker RC. Resurrecting free play in young children: looking beyond fitness and fatness to attention, affiliation, and affect. Archives of Pediatric and Adolescent Medicine. 2005;159(1):46-50.

8 Holloway SD, Reichhart-Erickson M. The relationship of day care quality to children's free-play behavior and social problem-solving skills. Early Childhood Research Quarterly. 1988;3(1):39-53.

9 Blatchford P, Baines E, Pellegrini A. The social context of school playground games: sex and ethnic differences, and changes over time after entry to junior school. British Journal of Developmental Psychology. 2003;21(4):481-505.

10 Little H, Wyver S. Outdoor play: does avoiding the risks reduce the benefits? Australasian Journal of Early Childhood. 2008;33(2):33-40.

11 Stratton G. Promoting children's physical activity in primary school: an intervention study using playground markings. Ergonomics. 2000;43(10):1538-46.

12 Sallis J, Prochaska J, Taylor W. A review of correlates of physical activity of children and adolescents. Medicine & Science in Sports & Exercise. 2000;32(5):963-75.

13 Aarts MJ, Wendel-Vos W, van Oers HA, van de Goor IA, Schuit AJ. Environmental determinants of outdoor play in children: a large-scale cross-sectional study. American Journal of Preventive Medicine. 2010;39(3):212-19.

14 Cleland V, Timperio A, Salmon J, Hume C, Baur LA, Crawford D. Predictors of time spent outdoors among children: 5-year longitudinal findings. Journal of Epidemiology and Community Health. 2010;64(5):400-6.

15 Bandura A. Social cognitive theory: an agentic perspective. Annual Review of Psychology. 2001;52(1):1-26.
16 Ajzen I. The theory of planned behavior. Organizational Behavior and Human Decision Processes. 1991;50(1):179-211.
17 Rosenstock IM, Strecher VJ, Becker MH. Social learning theory and the health belief model. Health Education and Behavior. 1988;15(2):175-83.
18 Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth: a review. American Journal of Preventive Medicine. 2011;41:442-55.
19 Hirasing RA, Bulk-Bunschoten AM, Renders CM. Youth Health Care Overweight Prevention Protocol. Youth Health Care Overweight Prevention Protocol. 2005, Amsterdam: VU Medisch Centrum.
20 Statistics Netherlands. Dutch Standard Classification of Education 2003. 2004, Voorburg/Heerlen, Netherlands: Statistics Netherlands.
21 Trost SG, Pate RR, Sallis JF, Freedson PS, Taylor WC, Dowda M, et al. Age and gender differences in objectively measured physical activity in youth. Medicine & Science in Sports & Exercise. 2002;34(2):350-5.
22 Sallis JF, Nader PR, Broyles SL, Berry CC, Elder JP, McKenzie TL, et al. Correlates of physical activity at home in Mexican-American and Anglo-American preschool children. Health Psychology. 1993;12(5):390-8.
23 Prochaska JO, DiClemente CC. Stages and processes of self-change of smoking: toward an integrative model of change. Journal of Consulting and Clinical Psychology. 1983;51(3):390-5.
24 Kutner MH, Nachtsheim C, Neter J. Applied Linear Regression Models. 2004, New York: McGraw-Hill/Irwin.
25 Giles-Corti B, Timperio A, Bull F, Pikora T. Understanding physical activity environmental correlates: increased specificity for ecological models. Exercise and Sport Sciences Review. 2005;33(4):175-81.
26 De Bourdeaudhuij I, Sallis JF, Saelens BE. Environmental correlates of physical activity in a sample of Belgian adults. American Journal of Health Promotion. 2003;18(1):83-92.
27 Maddison R, Mhurchu CN. Global positioning system: a new opportunity in physical activity measurement. International Journal of Behavioral Nutrition and Physical Activity. 2009;6(1):73.
28 Kremers SP, De Bruijn G-J, Visscher TL, Van Mechelen W, De Vries NK, Brug J. Environmental influences on energy balance-related behaviors: a dual-process view. International Journal of Behavioral Nutrition and Physical Activity. 2006;3(1):9.
29 Pikora T, Giles-Corti B, Bull F, Jamrozik K, Donovan R. Developing a framework for assessment of the environmental determinants of walking and cycling. Social Science and Medicine. 2003;56(8):1693-703.
30 Prins RG, Oenema A, van der Horst K, Brug J. Objective and perceived availability of physical activity opportunities: differences in associations with physical activity behavior among urban adolescents. International Journal of Behavioral Nutrition and Physical Activity. 2009;6(1):70.

31 Maddison R, Hoorn SV, Jiang Y, Mhurchu CN, Exeter D, Dorey E, et al. The environment and physical activity: the influence of psychosocial, perceived and built environmental factors. International Journal of Behavioral Nutrition and Physical Activity. 2009;6(1):19.

32 Chaix B, Méline J, Duncan S, Merrien C, Karusisi N, Perchoux C, et al. GPS tracking in neighborhood and health studies: a step forward for environmental exposure assessment, a step backward for causal inference? Health & Place. 2013;21:46-51.

33 Spence JC, Lee RE. Toward a comprehensive model of physical activity. Psychology of Sport and Exercise. 2003;4(1):7-24.

34 Bakker I, de Vries S, van den Bogaard C, van Hirtum W, Joore J, Jongert M. Playground van de Toekomst Succesvolle speelplekken voor basisscholieren. *Leiden, TNO* 2008

CHAPTER 5

Moderators of the longitudinal relationship between the perceived physical environment and outside play in children: the KOALA birth cohort study

This chapter has been published as:

Remmers T, Van Kann D, Gubbels JS, Schmidt S, de Vries SI, Ettema D, Kremers SP, Thijs C. Moderators of the longitudinal relationship between the perceived physical environment and outside play in children: the KOALA birth cohort study. International Journal of Behavioral Nutrition and Physical Activity. 2014:11(1);150.

Abstract

Objectives: Promoting unstructured outside play is a promising vehicle to increase children's physical activity (PA). This study investigates if factors of the social environment moderate the relationship between the perceived physical environment and outside play.
Study design: 1875 parents from the KOALA Birth Cohort Study reported on their child's outside play around age five years, and 1516 parents around age seven years. Linear mixed model analyses were performed to evaluate (moderating) relationships among factors of the social environment (parenting influences and social capital), the perceived physical environment, and outside play at age five and seven. Season was entered as a random factor in these analyses.
Results: Accessibility of PA facilities, positive parental attitude towards PA and social capital were associated with more outside play, while parental concern and restriction of screen time were related with less outside play. We found two significant interactions; both involving parent perceived responsivity towards child PA participation.
Conclusion: Although we found a limited number of interactions, this study demonstrated that the impact of the perceived physical environment may differ across levels of parenting responsibility.

Background

Physical activity (PA) is key to prevent and reverse childhood overweight and obesity, resulting in the incorporation of PA in international guidelines of the World Health Organization (i.e. 60 minutes of daily moderate to vigorously intense PA) (1). Despite the well-known benefits, about half of the children in the U.S. and the Netherlands do not meet this guideline (2-3).

Established correlates of children's PA behavior are male gender, PA enjoyment/preferences, and peer support (4-9). In addition, increasing evidence suggests that attributes of the perceived physical environment such as functionality, traffic safety, attractiveness, and accessibility are also associated with PA (10-13). Evidence for this relationship in children is however mixed (11, 13). This mixed evidence is greatly influenced by differences in the measurement of attributes of the physical environment and PA (objective versus subjective) and a lack of systematic investigation of moderators of environmental influences (14). In addition, several PA domains (e.g. outside play, organized sports, active transport) may have different environmental correlates (e.g. outside play is conceptually matched to playgrounds rather than active transport). Conceptual mismatching of attributes of the physical environment to specific PA domains may be another reason for the mixed evidence in children (15, 16).

Outside play (i.e. PA without any given tasks or goals; unstructured free play) is such a PA domain, that has been recommended as most appropriate to increase PA in young children (17). Outside play has been shown to contribute substantially to children's total PA levels (12, 18-23) also in different specific contexts such as school grounds, sports facilities, urban green space and active transport (24). In addition, outside play is positively associated with children's social skills as they learn to account for each other (25-27) and provides challenges that foster the development of new motor skills in a self-regulatory way (28). In order to promote outside play effectively, the determinants of this behavior should be examined. Three studies have examined correlates of outside play duration related to the physical and social environment, and have reported that the family environment (e.g. parental rules, parental attitudes regarding outside play) was the strongest construct of variables related to outside play, and that the perceived physical environment was considered promising in fostering PA, but they appear to explain a small proportion of outside play (29-31).

Based on several conceptual ecological frameworks and an umbrella review of Ding and colleagues (12-15), it is recommended to include potential moderators in the investigation of the relationship between physical environment and PA behavior (14). The perceived physical environment can directly influence children's outside play behavior, but the strength of this relationship may depend on activators / inhibitors of the social environment. More specifically, parents may play a crucial role in a child's relative exposure to the perceived physical environment, and thus also on outside play. Investigating the moderating influence of the social environment on the relationship between the perceived physical environment and outside play is thus a crucial next step in

understanding the mechanisms that underlie outside play. Based on results from other studies, some variables are of special interest. First, as young children's exposure to the neighborhood are considered relatively dependent on their parents, factors such as negative parental attitudes, worry or restrictions may attenuate the relationship between the perceived physical environment and outside play (14, 32, 33). Second, factors such as social capital in the neighborhood may strengthen the perceived physical environment – outside play relationship. Neighborhoods with high social capital may be able to reinforce social norms about the plural benefits of PA, and via these social norms – may have increased perceived safety in places where children are likely to regularly participate in outside play (34, 35). In addition, parents experiencing social cohesion may grant their child more autonomy in following up on their needs to play outside.

Consequently, the present study addresses the question to what extent the factors of the social environment – expressed as parenting influences and social capital – moderate the relationship between the parent-perceived physical environment and outside play in five and seven year-old children.

Methods

Study design and participants

This study is embedded in the KOALA Birth Cohort Study that follows a group of (originally) 2834 children of healthy pregnant women from the general population who participated in an ongoing prospective cohort study on pregnancy-related pelvic girdle pain. The study addresses two major themes; allergy / asthma, and growth / development. Children are located mainly in the south of the Netherlands, in municipalities of various sizes, including a variety of spatial settings (36). From the total KOALA-cohort (*N*=2834), 1875 parents provided information on their child's outside play around five years, and 1525 reported on their child's outside play around age seven years. As the perceived physical environment may not be longer valid for the second measurement when participants have moved, we omitted participants' measurements at follow up when moved home between baseline and follow-up (n=208, 13.6%). Consequently, follow-up of outside play was available for 1317 participants. All parents gave written informed consent. The present study was approved by the Medical Ethics Committee of Maastricht University Medical Center+.

Measurements

Perceived physical environment

Around child age of five years, parents completed a 48 items questionnaire assessing characteristics of the neighborhood environment. Perceived social as well as physical aspects of the environment were assessed through self-completed questionnaires. The construction of the questionnaire was based on the Neighborhood Environment

Walkability Scale but was modified to reflect the Dutch built environment, including items relevant to children (e.g. playgrounds, school yards, and dog waste) (37). A full description and reliability statistics of all scales can be found in Appendix 2, Table S1. Response scales were constructed according to level of agreement with statements like “Most streets in the neighborhood have cycle paths” or “The neighborhood is a real community”, and consist of five-point scales ranging from “I strongly disagree” to “I strongly agree”. Composite variables were created from individual items by the inspection of Cronbach’s alpha (between 0.70 and 0.80) and principal component analyses for potential constructs with a Cronbach’s alpha of at least 0.60 (38). The following constructs of the perceived physical environment were identified: accessibility (6-item sum score), functionality (6-item sum score), attractiveness (7-item sum score), satisfaction (3-item sum score), and traffic safety (4-item sum score). The use of each of these constructs is recognized in studies investigating the supportiveness of the environment for PA (11, 39, 40).

Social environment

Factors of the social environment were expressed as 1) parenting influences and 2) social capital. Parenting influences were assessed by a set of nine questions, based on the Dutch translation of the Child Feeding Questionnaire (CFQ) (41). The nutrition-related items of the CFQ were translated into a PA-related parenting questionnaire (42). Parenting influences were defined as the 1) perceived influence of the respondent and their partner on the PA behavior of their child (both 3-item sum scores), 2) attitude towards child PA (5-item sum score), 3) perceived responsibility regarding child PA (2-item sum score), 4) concern regarding child PA (3-item sum score), 5) restriction of child screen time (6-item sum score), 6) pressure towards child to be active (3-item sum score), and 7) monitoring of child PA (2-item sum score). Average reliability (Cronbach’s alpha) of these scales was 0.67, with a range of 0.57 – 0.93. A complete description and reliability statistic of these scales is presented in Appendix 2, Table S1.
Social capital was assessed by a set of five items, based on earlier empirical research on the influence of social capital on obesity and PA (43). Cronbach’s alpha for this scale was 0.87 (see Appendix 2, Table S1).

Outside play

Outside play was defined as the total duration of unstructured outside play in an average week, without organized sports, school physical education, and active transport. Outside play was assessed by questionnaire, both at child age five and seven years using an identical set of questions. First, parents were asked on how many days their child played outside in an average week for the last four weeks. The eight response categories ranged from “never or less than one day on average” till “seven days per week”. Second, parents were asked to indicate the average duration of outside play. The five response categories were: shorter than half an hour (computed as 15 minutes), half to one hour (computed as 45 minutes), one to two hours (computed as 90 minutes), two to three hours (computed as 150 minutes) and three hours or more (computed as 210 minutes). The frequency and duration of child outside play were multiplied to arrive at an average minutes of outside play per week. The date of completing the questionnaire was used to classify the season (i.e. winter, autumn, spring, and summer).

Statistical analyses

We first evaluated the association among outside play and all attributes of the perceived physical environment, and the social environment (parenting influences and social capital). To do this, we performed repeated measures linear mixed model analyses with outside play at age five and seven years as the dependent variable. We entered season of outside play measurement at age five and seven as a random factor. By doing so, we allowed each child to have its own random slope for season-combinations at five and seven years, while using an autoregressive (AR1) covariance structure. We examined all analyses using the following sequence: model 1) factor only adjusted for covariates (i.e. gender, maternal education, and child age); model 2) factor adjusted for covariates and all variables of their block (i.e. perceived physical environment versus parenting influences and social capital); 3) factor adjusted for covariates and all above described variables of the perceived physical environment, parenting influences and social capital (final model). We tested for moderation by entering interaction terms between each of the perceived physical environment variables, and each of the parenting influences and social capital variables, using the same repeated measures linear mixed model analyses as described above, with interaction terms for the moderators. We examined all potential moderating associations using the following sequence: model 1) interaction term only adjusted for main effects of the interaction and covariates; model 2) as 1, but also adjusted for previously defined statistically significant main effects; model 3) as 2, but also adjusted for previously defined non-significant main effects; 4) as step 3, but also adjusted for other statistically significant interaction terms in the model (final model). Finally, we stratified consistent significant interactions for interpretation purposes, using a median split.

Based on results from previous studies (11, 25, 44, 45), we investigated the potential confounding influence of seasonality (autumn, winter, spring, summer), gender, age of the child, and maternal education. For maternal education, categories were low (no education, primary school, or ≤ 3 years of general secondary school), mid-low (< 3 years of general secondary school), mid-high (higher vocational training, undergraduate programs, or bachelor's degree), and high (higher academic education) (46). None of these potential confounders were associated with a change of more than 10% in any of our coefficients after adjustment. However, to improve the precision of our models, these four variables were entered in our models as covariates (47).

To compare the relative strength of associations among variables, we used standardized coefficients in all models. We defined statistically significant moderation as $p < 0.10$ and a statistically significant association for main effects as $p < 0.05$. As we performed various model variations to investigate consistent significant interactions, correction for multiple testing was not applied. All analyses were performed with SPSS version 20.0 (IBM Corp., NY, USA).

Results

The total study sample consisted of 1875 children (Table 1). As almost all respondents are mothers of the child, the perceived influence of the respondent and partner on outside play is hereafter defined as perceived influence of the mother. In total, 91.1% of the participants had at least a mid-high educational level (i.e. higher vocational training, undergraduate programs, or Bachelor's degree) (46). Children had a mean age of 5.0 years (SD= 0.5) at baseline and 7.0 years (SD= 1.2) at follow-up and spent on average approximately 60 more minutes in outside play per week at seven years compared to five years of age (both boys and girls). Boys spent significantly more time in outside play than girls at both five and seven years ($p < 0.01$). There were significant differences in outside play duration between all seasons, at both five and seven years ($p < 0.01$ for both five and seven years, data not shown). Mean scores of each scale are presented in Apendix 2, Table S1.

Table 1: Characteristics of the study population

	Total		Boys		Girls	
	N	Mean (SD)	*n*	Mean (SD)	*n*	Mean (SD)
Age at baseline (years)	1875	5.0 (0.5)	956	5.0 (0.5)	919	5.0 (0.5)
Age at follow-up (years)	1407	7.0 (1.2)	714	7.1 (1.1)	693	7.0 (1.3)
Gender of parent (female)	1830	97.8%	935	97.7%	895	97.7%
Maternal education (missing *n* = 186)						
Low	4	0.2%	3	0.3%	1	0.1%
Mid-low	155	8.7%	81	8.9%	74	8.4%
Mid-high	687	38.4%	336	36.9%	351	39.9%
High	943	52.7%	490	53.8%	453	51.5%
Parent perceived neighborhood characteristics						
Satisfaction (range 1-5)	1875	3.8 (0.9)	956	3.8 (0.9)	919	3.8 (0.9)
Functionality (range 1-5)	1875	3.0 (0.8)	956	3.0 (0.8)	919	3.0 (0.8)
Traffic safety (range 1-5)	1875	3.3 (1.0)	956	3.2 (1,0)	919	3.3 (1.0)
Attractiveness (range 1-5)	1875	3.9 (0.6)	956	3.9 (0.6)	919	3.9 (0.5)
Accessibility (range 0-7) †	1875	3.4 (1.5)	956	3.4 (1.5)	919	3.4 (1.5)
Outside play at 5 years ‡	1875	619.2 (365.4)	956	648.6 (365.4)*	919	588.6 (363.1)*
Outside play at 7 years ‡	1317	683.5 (347.1)	664	708.8 (344.9)*	653	659.7 (347.9)*

† according to the number of facilities (forest, school, playground, playing field, (unpaved) gym or exercise facility, swimming pool) accessible for physical activity within 10 minutes of walking. ‡ presented as minutes per week. * difference = $p < 0.01$.

We investigated dropout differences between baseline and follow-up regarding all variables presented in Table 1 and Table S1. Respondents who dropped out were solely somewhat less restrictive of sedentary behaviors (mean score 3.02 versus 2.93; p=0.03), and had a somewhat older child (4.99 versus 5.08 years; p=0.01). At baseline, 97.8% of the respondents that filled in the questionnaire were mothers. Unfortunately we did not assess respondent’s gender at follow-up, and thus we were unable to account for potential differences in subsequent analyses. However, because in previous and subsequent annual questionnaires of the KOALA Birth Cohort the percentage of mothers

were all above 95%, one can confidently assume that the percentage mothers at our specific follow-up measurement was also above 95%.

Main effects of potential predictors of outside play

Perceived attractiveness of the neighborhood and accessibility of PA facilities were related to more (minutes of) outside play over a follow-up period of approximately two years (Table 2, model 1-3). When adjusted for parenting influences and social capital however, the association with attractiveness was attenuated (Table 2, final model). In contrast, accessibility remained statistically significant in all models, implying that outside play was associated with better accessibility of PA-related places within 10 minutes walking distance of home, independent of all variables presented in Table 2.

A positive parental attitude towards child PA was related to more outside play; independent of other parenting influences and factors of the perceived physical environment (Table 2). Social capital was also independently related to more outside play. By contrast, restriction of screen time and parental concern regarding child PA were independently related to less outside play. Restriction of screen time showed the strongest association with outside play of all variables examined: parents reported significant less outside play if they thought that they needed to actively restrict their child's screen time. Again, this association was independent of variables presented in Table 2.

Table 2. Associations among the perceived physical environment, parenting influences, social capital and child outside play development between five (*n*= 1875) and seven years (*n*= 1317).

	Model 1 std. beta (95% C.I.)	Model 2 std. beta (95% C.I.)	Model 2 std. beta (95% C.I.)	Final model std. beta (95% C.I.)
Functionality	−0.01 (-0.05 to 0.03)	−0.03 (-0.07 to 0.01)		−0.03 (-0.07 to 0.01)
Traffic safety	**0.07 (0.03 to 0.11)****	0.04 (-0.01 to 0.08)		0.03 (-0.02 to 0.07)
Attractiveness	**0.07 (0.03 to 0.12)****	**0.06 (0.02 to 0.10)***		0.01 (-0.04 to 0.05)
Accessibility	**0.06 (0.02 to 0.10)****	**0.06 (0.02 to 0.11)****		**0.05 (0.01 to 0.09)***
Attitude	**0.13 (0.09 to 0.17)****		**0.09 (0.05 to 0.13)****	**0.09 (0.05 to 0.13)****
Perceived responsibility	0.002 (-0.04 to 0.04)		0.01 (-0.03 to 0.05)	0.01 (-0.04 to 0.05)
Concern	**−0.13 (-0.17 to -0.09)****		**−0.04 (-0.09 to -0.01)***	**−0.04 (-0.09 to -0.001)***
Restriction	**−0.24 (-0.28 to -0.20)****		**−0.22 (-0.26 to -0.17)****	**−0.21 (-0.26 to -0.17)****
Pressure	**0.06 (0.02 to 0.10)****		0.04 (-0.002 to 0.08)	0.04 (-0.01 to 0.08)
Monitoring	−0.02 (-0.06 to 0.02)		−0.01 (-0.05 to 0.03)	−0.01 (-0.05 to 0.03)
Social capital	**0.12 (0.08 to 0.16)****		**0.08 (0.04 to 0.12)****	**0.07 (0.03 to 0.11)****

Standardized coefficients from repeated measures linear mixed models. Dependent variable is outside play at five and seven years. Season at five and seven was entered as random factor, allowing each respondent to have its own random slope for season-combinations, using an autoregressive covariance structure. Model 1 is only adjusted for covariates (gender, maternal education, and child age). Model 2 is adjusted for covariates and all variables in their block (second and third column). Final model is adjusted for covariates and all variables in the table. *: $p < 0.05$, **: $p < 0.01$.

Table 3. Moderators of the longitudinal relationship between the perceived physical environment and child outside play between five (*n*= 1875) and seven years (*n*= 1317).

Interaction terms	Model 1 std. beta (90% C.I.)	Model 2 std. beta (90% C.I.)	Model 3 std. beta (90% C.I.)	Final model std. beta (90% C.I.)
Functionality * perceived responsibility	**0.034 (0.001 to 0.063)°**	**0.038 (0.008 to 0.068)***	**0.041 (0.011 to 0.070)***	**0.035 (0.004 to 0.066)°**
Traffic safety * perceived responsibility	0.031 (-0.019 to 0.064)	**0.033 (0.001 to 0.65) °**	**0.039 (0.005 to 0.070)***	0.031 (-0.002 to 0.064)

Standardized coefficients from repeated measures linear mixed models. Dependent variable is outside play at five and seven years. Season at five and seven was entered as random factor, allowing each respondent to have its own random slope for season-combinations, using an autoregressive covariance structure.
Model 1 is only adjusted for covariates (gender, maternal education, and child age) and main effects of the interaction. Model 2 is adjusted for covariates significant main effects of Table 2 (accessibility, attitude, concern, restriction, social capital). Model 3 contains covariates and all main effects of Table 2. Final model is equal to Model 2, but interactions are also adjusted for each other. °: $p < 0.10$, *: $p < 0.05$.

Moderating relationships between potential predictors of outside play

Two combinations of variables demonstrated moderation between the perceived physical environment, parenting influences and social capital in the amount of outside play at age five and seven (Table 3, model 1-4).

Perceived responsibility moderated the perceived environmental influence of functionality on outside play, consistently across all models (Table 3). When stratified, children from parents with high responsibility regarding their child's outside play demonstrated that functionality was related with more outside play (0.04, 95%C.I.= −0.07 to 0.15), while among parents with low responsibility, functionality was related with a less outside play (-0.03, 95%C.I.= −0.09 to 0.04).

Next to functionality also traffic safety showed interaction with perceived responsibility, but this only appeared after adjustment for main effects (Model 3) and slightly attenuated after adjustment for the other interactions (Model 4). Stratification showed that high responsibility strengthened the association between traffic safety and outside play (0.10, 95%C.I.= −0.03 to 0.23) versus (standardized beta 0.06, 95%C.I.= −0.003 to 0.12). Note that stratified models are adjusted for child age, child gender, and maternal education. In both strata, main effects were not statistically significant.

Discussion

This study has investigated the extent to which the social environment – expressed as parenting influences and social capital - moderated the relationship between the perceived physical environment and the development of children's outside play between five and seven years. We have showed that accessibility of PA facilities, positive parental attitude towards PA and social capital were associated with more outside play, while parental concern with respect to child PA participation and especially restriction of screen time were related with less outside play.

Although we only found a limited number of relatively weak interactions, this study demonstrated that the impact of the perceived physical environment might differ across levels of parenting responsibility. More specifically, this study showed that among children with parents with high responsibility towards their child PA, functionality of the neighborhood was related to more outside play; while in children with parents with low responsibility towards their child PA level, functionality was related to less outside play. The latter may reflect that functionality in the present study may be merely associated with a relative paucity of non-predefined public open space where children can play outside. This is supported by qualitative evidence that the usage of public open space depend on the child needing to cross busy roads (48). On the other hand, parents who feel responsible for the amount of their child PA may deliberately provide their child with the autonomy to play outside at spaces that they think are appropriate and safe.

One study specifically reported on the fairly minor influence of the perceived physical environment on outside play, and reported that the social environment overpowered the perceived physical environment in explaining outside play behavior (31). This is, to some extent, in line with the results of our study, which showed that the influence of the attractiveness of the neighborhood was attenuated when adjusted for parenting influences and social capital. In addition, previous research supports our finding that parental attitude is an important predictor of a higher amount of child outside play (33, 49). The evidence for the importance of social capital on child PA and especially outside play is scarce. It however seems plausible that social capital directly influences child outside play via the availability of more social contacts in the neighborhood, and indirectly influences child outside play by decreasing parental worries related to social safety ('stranger danger').

Parental restriction of screen time was strongly associated with less outside play at age five and seven. This seems in contrast to one previous study that highlighted the importance of parental rules in regulation of outside play (31). However, in the present study these 'rules' have a restrictive character, which may be less suitable for promoting outside play than positively formulated, supportive rules. This resembles previous findings from the KOALA study that parental restriction of sedentary activities was related to more sedentary behavior, whereas parental promotion of PA was associated with more activity (42). This is also in line with studies regarding child feeding and snacking behavior, which showed that parental restriction of screen time was related with increased child snack consumption, energy intake and body weight (50, 51). In addition, personal factors such as PA enjoyment or peer support from other children may also exert great influence on child outside play, and perhaps even attenuate our associations of interest (4).

Our findings regarding moderation of parenting influences and perceived physical environment in the regulation of outside play behavior are in line with the ecological perspective on energy balance related behaviors (52, 53) and PA specifically (54). However, we only found a limited number of relatively weak interactions. To date, studies on the moderating factors within the perceived physical environment regarding PA remain scarce (14). The few studies investigating these moderating factors are often incorporated within additional analyses of an intervention study, and mainly focused on socio-demographical factors (i.e. gender, age and race) (14, 55), which prohibits a valid comparison of our findings regarding the moderating influences of parenting influences and social capital with other studies. In line with recent advances in the field of parenting influences on child nutrition which reported upon moderations between general parenting style and specific parenting practices (56, 57), future studies are encouraged to focus on moderation among social environmental factors, and between the social and the (perceived) physical environment (14). In addition, attributes of the perceived physical environment may also interact with each other (e.g. relative accessibility of PA places may become less important if they are highly attractive). Based on recent work in the field of moderation of health behaviors, we suggest that social environmental factors (and especially parenting influences) act as a gatekeeper in the exposure of children to the

perceived physical environment, and thus moderates its influence on PA and outside play (14, 58).

Strengths and weaknesses

Strengths of the present study are, first, the consistent approach of investigating the relationship among the perceived physical environment, parenting influences, social capital, and outside play. Second, this study addresses the moderating influences of the parenting influences and social capital, which is relatively new in the field of health behaviors. Third, a longitudinal design was used, providing insight into associates and moderating factors regarding outside play development across a two-year period.

This study had some limitations; namely the relatively high educational level in the KOALA Birth Cohort Study (59) may limit generalization of our results with studies that included participants with relatively lower educational levels. Our dropout analyses showed that there was no important selective dropout and that attrition of was not likely to have influenced our results.

We used the meteorological seasons (i.e. autumn, winter, spring, and summer) to adjust for seasonality. However, more precise adjustment for weather-related burdens for children to perform outside play or PA (e.g. rainfall, temperature, and sunshine) may be available. As appropriate adjustment for seasonality is essential in studies investing PA (44), future studies are encouraged to examine the relative influence of these weather conditions on PA and outside play and the role of these weather conditions as a confounder.

The comparability of the standardized beta coefficients across model variations indicates consistency and statistical rigor of our models. We acknowledge that our effect sizes were relatively small. However, these small standardized effect sizes may be underestimated due to the relatively high error variance in the parent reported variables (main variables, moderators as well as outcomes). In addition, by allowing respondents to indicate the duration of outside play in five response categories, some measurement error is introduced and precision is compromised. These errors may be subsequently magnified by the multiplication effect regarding the assessment of the frequency of outside play. We thus encourage future studies to improve the reliability and precision of these parental reports by external validation with recent technological advances, examining test-retest methodologies or asking both the father and mother to report on their child's outside play independently.

To date, outside play can only be assessed by parent reports, as a distinction between outside play and other types of PA cannot be made by the currently used objective measurements (e.g. accelerometers or heart-rate monitors). However, recent technological advances provide opportunities for combining global positioning system (GPS), Geographic Information Systems (GIS), and accelerometers. One recent study managed to apply these recent methodologies in an objective measurement instrument

of outside play, and investigated differences in child gender, age, and comparisons with solely accelerometer-based MVPA (24). Future studies are encouraged to replicate this methodology and move on to investigate the influence of the (perceived) physical environment and / or social environment on objective outside play behavior.

Regarding the relative contribution of outside play to the total PA, one study recently investigated the relationship between the amount of parent reported outside play and the amount of accelerometer-measured PA. This study reported that more outside play (<1 hour per day versus 1-2 hours per day and >2 hours per day) was related with significantly lower sedentary time and higher PA of both light and moderate-to-vigorous intensity (22). In addition, only one study has estimated the proportion of strenuous PA during outside play in an intervention promoting outside play using special playgrounds and it has reported that approximately 35% of the time spent in outside play was moderate to vigorously active (60). Future studies are encouraged to quantify the contribution of outside play, relative to total PA and other PA domains.

It should be noted that this study solely focused on outside play. Therefore, these results are not generalizable to other PA domains such as organized sports and active transport. Outside play cannot be directly associated with the earlier established benefits of PA, such as its relationship with childhood obesity. Nonetheless, considering its multiple benefits such as increased PA (21), motor abilities, and social skills (25-27), outside play arguably contributes to improved childhood health in the long run.

Acknowledgements

We would like to thank the children and parents that participated in this part of the KOALA Birth Cohort Study. The authors declare that they have no competing interest

References

1. WHO. Global recommendations on physical activity for health. World Health Organization 2010:8-10.
2. Bernaards C. Bewegen in Nederland 2000-2010-Resultaten TNO-Monitor Bewegen en Gezondheid (Physical citivty in the Netherlands 2000-2010: results from the monitor physical activity and health). 2011, Leiden: TNO.
3. Pate RR, Freedson PS, Sallis JF, Taylor WC, Sirard J, Trost SG, et al. Compliance with physical activity guidelines: prevalence in a population of children and youth. Annals of Epidemiology. 2002;12(5):303-8.
4. Sallis JF, Prochaska JJ, Taylor WC. A review of correlates of physical activity of children and adolescents. Medicine & Science in Sports & Exercise. 2000;32:963-75.
5. DiLorenzo TM, Stucky-Ropp RC, Vander Wal JS, Gotham HJ. Determinants of exercise among children. II. A longitudinal analysis. Preventive Medicine. 1998;27(3):470-7.

6. Ross JG, Pate RR. The National Children an Youth Fitness Study: a summary of findings. Journal of Physical Education, Recreation & Dance. 1987;56(1):44-90.
7. Riddoch CJ, Andersen LB, Wedderkopp N, Harro M, Klasson-Heggebo L, Sardinha LB. et al. Physical activity levels and patterns of 9-and 15-yr-old European children. Medicine & Science in Sports & Exercise. 2004;36(1):86-92.
8. Van der Horst K, Paw M, Twisk JW, Van Mechelen W. A brief review on correlates of physical activity and sedentariness in youth. Medicine & Science in Sports & Exercise. 2007;39(8):1241-50.
9. Trost SG, Pate RR, Sallis JF, Freedson PS, Taylor WC, Dowda M, et al.. Age and gender differences in objectively measured physical activity in youth. Medicine & Science in Sports & Exercise. 2002;34(2):350-5.
10. Humpel N, Owen N, Leslie E. Environmental factors associated with adults' participation in physical activity: a review. American Journal of Preventive Medicine. 2002;22(3):188-99.
11. Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth: a review. American Journal of Preventive Medicine. 2011;41(4):442-55.
12. Brown WH, Pfeiffer KA, McIver KL, Dowda M, Addy CL, Pate RR. Social and environmental factors associated with preschoolers' nonsedentary physical activity. Child Development. 2009;80(1):45-58.
13. Davison K, Lawson C. Do attributes in the physical environment influence children's physical activity? A review of the literature. International Journal of Behavioral Nutrition and Physical Activity. 2006;3(1):19.
14. Gubbels J, Van Kann DH, de Vries NK, Thijs C, Kremers SP. The next step in health behavior research: the need for ecological moderation analyses - an application to diet and physical activity at childcare. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1):52.
15. Giles-Corti B, Timperio A, Bull F, Pikora T. Understanding physical activity environmental correlates: increased specificity for ecological models. Exercise and Sport Sciences Reviews. 2005;33(4):175-81.
16. De Vries SI, Hopman-Rock M, Bakker I, Hirasing RA, Van Mechelen W. Built environmental correlates of walking and cycling in Dutch urban children: results from the SPACE study. International Journal of Environmental Research and Public Health. 2010;7(5):2309-24.
17. Barlow SE, Dietz WH. Obesity evaluation and treatment: expert committee recommendations. Pediatrics. 1998;102(3):29.
18. Wickel EE, Eisenmann JC: Contribution of youth sport to total daily physical activity among 6-to 12-yr-old boys. Medicine & Science in Sports & Exercise. 2007;39(9):1493-1500.
19. Hinkley T, Crawford D, Salmon J, Okely AD, Hesketh K. Preschool children and physical activity: a review of correlates. American Journal of Preventive Medicine. 2008;34(5):435-41.

20. Mackett RL, Lucas L, Paskins J, Turbin J. The therapeutic value of children's everyday travel. Transportation Research Part A: Policy and Practice. 2005;39(2):205-19.
21. Page A, Cooper A, Griew P, Davis L, Hillsdon M. Independent mobility in relation to weekday and weekend physical activity in children aged 10-11 years: the PEACH Project. International Journal of Behavioral Nutrition and Physical Activity. 2009;6(1):2.
22. Stone MR, Faulkner GE. Outdoor play in children: Associations with objectively-measured physical activity, sedentary behavior and weight status. Preventive Medicine. 2014;65:122-27.
23. Schaefer L, Plotnikoff RC, Majumdar SR, Mollard R, Woo M, Sadman R, et al. Outdoor Time Is Associated with Physical Activity, Sedentary Time, and Cardiorespiratory Fitness in Youth. The Journal of Pediatrics. 2014;165(3)516-21.
24. Klinker CD, Schipperijn J, Kerr J, Ersbøll AK, Troelsen J. Context-specific outdoor time and physical activity among school-children across gender and age: Using accelerometers and GPS to advance methods. Frontiers in Public Health. 2014;2(20).
25. Burdette HL, Whitaker RC. Resurrecting free play in young children: looking beyond fitness and fatness to attention, affiliation, and affect. Archives of Pediatrics & Adolescent Medicine. 2005;159(1):46-50.
26. Holloway SD, Reichhart-Erickson M. The relationship of day care quality to children's free-play behavior and social problem-solving skills. Early Childhood Research Quarterly. 1988;3(1):39-53.
27. Blatchford P, Baines E, Pellegrini A. The social context of school playground games: Sex and ethnic differences, and changes over time after entry to junior school. British Journal of Developmental Psychology. 2003;21(4):481-505.
28. Little H, Wyver S: Outdoor Play. Does Avoiding the Risks Reduce the Benefits? The Australasian Journal of Early Childhood. 2008;33(2):33-40.
29. Aarts M, Wendel-Vos W, van Oers HA, van de Goor IAM, Schuit AJ. Environmental determinants of outdoor play in children: a large-scale cross-sectional study. American Journal of Preventive Medicine. 2010;39(3):212-19.
30. Cleland V, Timperio A, Salmon J, Hume C, Baur LA, Crawford D. Predictors of time spent outdoors among children: 5-year longitudinal findings. Journal of Epidemiology & Community Health. 2010;64(5):400-6.
31. Remmers T, Broeren SM, Renders CM, Hirasing RA, van Grieken A, Raat H. A longitudinal study of children's outside play using family environment and perceived physical environment as predictors. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1):76.
32. Dempsey JM, Kimiecik JC, Horn TS. Parental Influence on Children's Moderate to Vigorous Physical Activity Participation: An Expectancy-Value Approach. Pediatric Exercise Science. 1993;5(2)151-67.
33. Kimiecik JC, Horn TS. Parental beliefs and children's moderate-to-vigorous physical activity. Research Quarterly for Exercise and Sport. 1998;69(2):163-75.

34. McNeill LH, Kreuter MW, Subramanian SV. Social Environment and Physical activity: a review of concepts and evidence. Social Science and Medicine. 2006;63(4):1011-22.
35. Berkman LF, Kawachi I, Glymour MM. Social epidemiology. New York: Oxford University Press 2000.
36. Cremers E, Thijs C, Penders J, Jansen E, Mommers M. Maternal and child's vitamin D supplement use and vitamin D level in relation to childhood lung function: the KOALA Birth Cohort Study. Thorax. 2011;66(6):474-80.
37. Rosenberg D, Ding D, Sallis JF, Kerr J, Norman GJ, Durant N, et al. Neighborhood Environment Walkability Scale for Youth (NEWS-Y): reliability and relationship with physical activity. Preventive Medicine. 2009;49(2):213-8.
38. Schmidt S, Sleddens EF, de Vries SI, Gubbels JS, Thijs C. The relationship between the neighborhood and body weight development in children: the KOALA Birth Cohort Study Manuscript submitted for publication. 2014.
39. Kirtland KA, Porter DE, Addy CL, Neet MJ, Williams JE, Sharpe PA, et al. Environmental measures of physical activity supports: perception versus reality. American Journal of Preventive Medicine. 2003;24(4):323-31.
40. Addy CL, Wilson DK, Kirtland KA, Ainsworth BE, Sharpe P, Kimsey D. Associations of perceived social and physical environmental supports with physical activity and walking behavior. American Journal of Public Health. 2004;94(4):440-3.
41. Birch LL, Fisher J, Grimm-Thomas K, Markey C, Sawyer R, Johnson S. Confirmatory factor analysis of the Child Feeding Questionnaire: a measure of parental attitudes, beliefs and practices about child feeding and obesity proneness. Appetite. 2001;36(3):201-10.
42. Gubbels JS, Kremers SP, Stafleu A, de Vries SI, Goldbohm RA, Dagnelie PC, et al. Association between parenting practices and children's dietary intake, activity behavior and development of body mass index: the KOALA Birth Cohort Study. International Journal of Behavioral Nutrition and Physical Activity. 2011;8(1):18.
43. Kim D, Subramanian S, Gortmaker SL, Kawachi I. US state-and county-level social capital in relation to obesity and physical inactivity: a multilevel, multivariable analysis. Social Science and Medicine. 2006;63(4):1045-59.
44. Tucker P, Gilliland J. The effect of season and weather on physical activity: a systematic review. Public Health. 2007;121(12):909-22.
45. Gordon-Larsen P, McMurray RG, Popkin BM. Determinants of adolescent physical activity and inactivity patterns. Pediatrics. 2000;105(6):83.
46. Statistics Netherlands. Dutch Standard Classification of Education 2003. Voorburg/Heerlen: Statistics Netherlands 2004.
47. Maldonado G, Greenland S. Simulation study of confounder-selection strategies. American Journal of Epidemiology. 1993;138(11):923-36.
48. Veitch J, Bagley S, Ball K, Salmon J. Where do children usually play? A qualitative study of parents' perceptions of influences on children's active free-play. Health & Place. 2006;12(4):383-93.

49. Trost SG, Sallis JF, Pate RR, Freedson PS, Taylor WC, Dowda M. Evaluating a model of parental influence on youth physical activity. American Journal of Preventive Medicine. 2003;25(4):277-82.
50. Fisher JO, Birch LL. Parents' restrictive feeding practices are associated with young girls' negative self-evaluation of eating. Journal of the American Dietetic Association. 2000;100(11):1341-6.
51. Fisher JO, Birch LL. Restricting access to foods and children's eating. Appetite. 1999;32(2):405-19.
52. Pikora T, Giles-Corti B, Bull F, Jamrozik K, Donovan R. Developing a framework for assessment of the environmental determinants of walking and cycling. Social Science and Medicine. 2003;56(8):1693-703.
53. Kremers SP, De Bruijn G-J, Visscher TL, Van Mechelen W, De Vries NK, Brug J. Environmental influences on energy balance-related behaviors: a dual-process view. International Journal of Behavioral Nutrition and Physical Activity. 2006;3(1):9.
54. Spence JC, Lee RE. Toward a comprehensive model of physical activity. Psychology of Sport and Exercise. 2003;4(1):7-24.
55. Kremers SP, de Bruijn G-J, Droomers M, van Lenthe F, Brug J. Moderators of Environmental Intervention Effects on Diet and Activity in Youth. American Journal of Preventive Medicine. 2007;32(2):163-72.
56. Darling N, Steinberg L. Parenting style as context: An integrative model. Psychological Bulletin. 1993;113(3):487.
57. Sleddens EF, Gerards SM, Thijs C, Vries NK, Kremers SP. General parenting, childhood overweight and obesity-inducing behaviors: a review. Pediatric Obesity. 2011:6:12-27.
58. Gubbels JS, Kremers SP, Van Kann DH, Stafleu A, Candel MJ, Dagnelie PC, et al. Interaction between physical environment, social environment, and child characteristics in determining physical activity at child care. Health Psychology. 2011;30(1):84.
59. Kummeling I, Thijs C, Penders J, Snijders BE, Stelma F, Reimerink J, et al. Etiology of atopy in infancy: the KOALA Birth Cohort Study. Pediatric Allergy and Immunology. 2005;16(8):679-84.
60. Bakker I, de Vries SI, van den Bogaard C, van Hirtum W, Joore J, Jongert M. Playground van de Toekomst Succesvolle speelplekken voor basisscholieren. Leiden, TNO 2008.

CHAPTER 6

Daily weather and children's physical activity patterns

This chapter has been published as:

Remmers T, Thijs C, Timperio A, Salmon J, Veitch J, Kremers SP, Ridgers ND. Daily weather and Children's physical activity patterns. Medicine & Science in Sports & Exercise. 2017;49(5):922-29.

Abstract

Introduction: Understanding how the weather affects physical activity (PA) may help in the design, analysis and interpretation of future studies, especially when investigating PA across diverse meteorological settings and with long follow-up periods. The present longitudinal study first aims to examine the influence of daily weather elements on intra-individual PA patterns among primary school children across four seasons, reflecting day-to-day variation within each season. Second, we investigate whether the influence of weather elements differs by day of the week (weekdays vs. weekends), gender, age, and Body Mass Index.

Method: PA data were collected by ActiGraph accelerometers for one week in each of four school terms that reflect each season in southeast Australia. PA data from 307 children (age range 8.7-12.8 years) were matched to daily meteorological variables obtained from the Australian Government's Bureau of Meteorology (maximum temperature, relative humidity, solar radiation, day length, and rainfall). Daily PA patterns and their association with weather elements were analyzed using multilevel linear mixed models.

Results: Temperature was the strongest predictor of moderate- and vigorous PA, followed by solar radiation and humidity. The relation with temperature was curvilinear, showing optimum PA levels at temperatures between 20 and 22 degrees Celsius. Associations between weather elements on PA did not differ by gender, child's age, or Body Mass Index.

Conclusions: This novel study focused on the influence of weather elements on intra-individual PA patterns in children. As weather influences cannot be controlled, knowledge of its impact on individual PA patterns may help in the design of future studies, interpretation of their results, and translation into PA promotion.

Introduction

The importance of regular physical activity (PA) and the range of associated short- and long-term benefits in children and adolescents is now globally established and accepted (16, 29). However, many children in Western Countries are insufficiently active (13), with inactivity tending to track from youth to adulthood (17). This makes the promotion of children's PA a critical health promotion target. In order to develop effective interventions to increase PA, it is important to understand why, when, and how much PA is performed. The development and validation of accelerometers has been an important contribution to this, as accelerometers can provide rich and objective data over extended periods of time (4).

An important complicating aspect for studies seeking to identify determinants of children's PA patterns stems from variability in weather conditions. This may be particularly problematic for studies exploring determinants of PA that takes place outdoors. For example, relationships between aspects of walkability and active transport may be moderated by the weather as children may be more likely to walk to school instead of using motorized transport in favorable weather conditions (22). Lack of consideration of weather conditions may compromise the findings of observational studies and influence intervention outcomes. Hence, understanding how the weather affects PA may help future studies to analyze and interpret PA patterns, especially when measuring across diverse meteorological settings and with long follow-up periods. In addition, studies investigating the influence of the weather may help future interventions to target inactive periods to overcome weather-related PA declines (9, 25).

The majority of studies that have examined weather and objectively-measured PA behavior in children have focused on seasonality (5, 25). Most European studies have generally found that PA is highest in summer and lowest in winter, but results from other continents are inconsistent (25). This inconsistency may be explained by scheduling of organized sports or school curricula (6, 26), or regional differences in specific weather elements (e.g. rainfall, temperature, wind, relative humidity, etc.) (11, 25). International comparisons are limited as average weather conditions within season vary considerably across the world (21). Consequently, although season is a proxy for general differences in weather conditions, seasonal variation does not fully capture the temporal influence of weather on PA behavior. In contrast to seasonal differences, consideration of the influence of actual daily weather elements (e.g. temperature, humidity, solar radiation) does enable international comparisons (21), and provides more detailed information about weather-related differences in children's PA. The investigation of weather elements and their influence on activity levels is therefore warranted (5, 19).

To the best of our knowledge, only the studies of Goodman et al. (12), Duncan et al. (9), Harrison et al. (14, 15), and Lewis et al. (21) have focused on weather elements by matching daily meteorological data to accelerometer measurements in children. However, in three studies data were only collected during a single measurement period (i.e. only

one season; (9, 12, 21). Single measurement periods may lack variability in weather elements, and may not reflect yearly (season-related) variability of weather elements (9). Studies measuring PA within a wide timespan using multiple measurement periods across seasons are needed to investigate the full range of these weather elements. In addition, the three studies described above focused on explaining variability between children (i.e. inter-individual variability) (9, 12, 21), but PA also shows considerable day-to-day variation within children (i.e. intra-individual variability) (12). As the influence of weather on children's PA patterns is a complex interplay between inter- and intra-individual relationships (24), understanding these relationships requires both knowledge from intra-individual, as well as inter-individual mechanisms. Finally, it is also of interest to see whether different effects may occur in population subgroups. For example, overweight or obese children may experience physical complaints or insecurity as a more proximal barrier to perform PA (irrespective of more distal weather elements) (8).

The present study first aims to examine intra-individual associations between daily weather elements and children's PA across a one-year timespan that reflects variability of weather across four seasons. Our second aim was to examine whether the influence of weather elements differs by day of the week (weekdays vs. weekends), gender, age, and Body Mass Index (BMI).

Methods

Procedures and participants

Primary schools located within a 40km radius of the Melbourne Central Business District, Australia, and with enrolments of greater than 200 pupils were identified and stratified into tertiles of socioeconomic status (SES) based on postcode using the Socio-Economic Index for Areas (1). In 2012, schools were randomly selected from each SES strata and invited to participate in the Patterns of Habitual Activity across Seasons (PHASE) study, which used a repeated measures design to examine seasonal changes in children's activity levels (26). Nine schools (one low, three medium, and five high SES) agreed to participate in the study and the school Principal provided written informed consent. Ethical approval for the study was provided by Deakin University Human Ethics Advisory Group Committee (HEAG), the Department of Education and Early Childhood Development, and the Catholic Education Office (Melbourne).

All children in Years 4 and 5 (aged 8-11 years) were invited to participate in the study (n=1270). Parental written informed consent was provided for 326 children (162 boys, 164 girls; 25.7% response rate) to participate in at least one component of the study at baseline (i.e. accelerometers, inclinometers, survey, anthropometry, focus groups). No information was obtained about non-responders as it is an ethical requirement in Australia for active informed consent to be provided. Data were collected from children during four school terms that closely correspond with each season in south-east Australia: Winter (August-September 2012; Term 3); Spring (October-November 2012; Term 4);

Summer (February-March 2013; Term 1); and Autumn (May-June 2013; Term 2). No data were collected during school holidays.

Measurements

Physical activity

Children's PA was objectively assessed for seven consecutive days in each school term using hip-mounted ActiGraph GT3X+ accelerometers (Pensacola, FL). Raw tri-axial data were sampled at 30Hz and downloaded and processed into 15 second epochs using ActiLife software (v6). Non-wear time was defined as sustained 20 minute periods of consecutive zero counts (4). Intensity of PA was classified using the following age-specific cut-points agreeing with metabolic equivalents (METs) (10): 1.5-3.99 for light PA (LPA), 4–5.99 for moderate PA (MPA), ≥ 6 for vigorous PA (VPA). These cut-points have been found to exhibit excellent classification accuracy and are commonly used (30). A valid day was defined as ≥ 8 hours on weekdays and ≥ 7 hours on weekend days. The lower weekend wear time requirement was due to children typically waking later on weekend days (26). For the purpose of this study, all valid days collected from each school term were included in the analyses.

Anthropometry

Body mass was measured to the nearest 0.1 kg using a calibrated electronic scale (Tanita BC-351; Tanita, Japan). Stature was measured to the nearest 0.1 cm using SECA portable stadiometers (model 217; SECA, Germany). Two measurements of body mass and stature were taken and averaged before calculating BMI (weight/stature^2, kg/m^2). In the event of a discrepancy over 0.1 kg or 1 cm, a third measurement was taken. All measurements were taken by trained research staff using standardized procedures.

Meteorological data

Meteorological data were obtained for each day of data collection from the publicly accessible Australian Government's Bureau of Meteorology (2). The nearest weather station to each participating school was identified and data were matched to accelerometer wear days in each school. The data obtained were temperature (daily maximum in °C), relative humidity (daily average in percentage), solar radiation (daily total in MJ/m^2), day length (total minutes of daylight per day), and rainfall (daily total in mm). Owing to its highly skewed distribution, rainfall was collapsed into three categories; no rainfall (52.5% of days); and rainfall split into categories of similar size: 0.1-7.8 mm (23.6% of days) and 7.9–46.0 mm per day (23.9% of days). All other weather-variables were treated as continuous variables in subsequent models.

Statistical analyses

Days were used as the unit of analysis because this allows day to day variation within children. Our primary outcome variables were (continuous) daily total minutes classified as MPA and VPA. Temperature, relative humidity, rainfall, solar radiation, and day length

were the primary (fixed) explanatory variables. Analyses were generally adjusted for accelerometer daily weartime, school term, gender, age and BMI.

Our primary aim was to analyze day-to-day PA variation within individual children (intra-individual variation). Therefore we adjusted for differences between individual children in our model (such as variation related to differences between schools) by allowing multilevel linear mixed models to compute a random intercept for each child, and a repeated term for each child across each day of measurement. Theoretically, as a result of investigating day-to-day variation within children using the model specified, additional adjustment for between-subject variables (such as school or gender) would not improve the model, nor the estimation of our relationship of interest. We found homogenous variances but decreasing covariances with increasing distance between repeated measurements; therefore we accounted for the covariance between repeated measures by specifying an autoregressive (AR1) covariance structure. Linearity was evaluated for each association, and in the case of curvilinear relationships, quadratic terms were fitted (21).

Multi-collinearity was investigated using linear regression analyses. With Variance Inflation Factors (VIF) ranging between 3.9 and 4.4, day length and temperature revealed highest multi-collinearity statistics, followed by solar radiation (VIF 3.0). Only removing day length from the model led to notable reduction in multicollinearity statistics (VIF's 2.8 and 2.3 for solar and temperature, respectively). We decided to retain all variables in subsequent analyses, as all Variance Inflation Factors were under 4.4 (20).

Potential moderation of gender, age, and BMI, as well as mutual moderation between weather variables (e.g. temperature and relative humidity) was evaluated by systematically investigating interactions and changes in model fit. BMI was dropped from the models investigating MPA as its initial main effect was not statistically significant. Advancing from the multi-collinearity statistics computed earlier, we compared results from models with- and without day length, to investigate whether potential collinearity between temperature and day length would have influenced these interactions. However, as both model-variations were highly comparable (data not shown), we retained day length in subsequent interaction models. Finally, we repeated our analyses for light PA and sedentary time. For all analyses, SPSS 21.0 for Windows (IBM SPSS Inc., Armonk, NY) was used, and $p<0.05$ indicated statistical significance.

Results

In total, 307 of 326 children (52% girls) provided valid PA data (≥1 day) in at least one school term and were included in the analyses. The average age was 11.14 years (SD=0.67, range=8.7-12.8) among boys and 11.10 years (SD = 0.68) among girls. In total, 24.7% of the boys and 15.9% of the girls were classified as overweight and 5.3% of the boys and 7.6% of the girls were classified as obese, according to International Obesity Taskforce thresholds for BMI (7).

As we included all valid days in the analyses, participants were allowed to have from one to seven days of consecutive monitoring per school term. In total, 69% of participants had valid data for at least four days and 40% had valid data for seven days across the four school terms. Children provided 4,597 days of PA measurement in total, with 31.8% in winter, 27.9% in spring, 21.2% in summer, and 19.1% in autumn. In total, 156 children (50.8%) provided data at all four school terms, 81 (26.4%) in three, and 54 (17.6%) in two and 16 (5.2%) in one school term.

PA and weather elements across the school terms are presented in Table 1. In winter and spring terms, children engaged in significantly more MPA compared to summer and autumn (p-values < 0.01). In addition, VPA differed significantly across all terms, except for spring versus autumn. VPA was highest in winter, following by spring/autumn, and summer.

Weather elements and children's PA patterns

In Table 2, relationships between weather elements and PA are presented. Compared to no rainfall, little rainfall (0.1–7.8 mm) was associated with more MPA and VPA, whereas more rainfall (7.9-46.0 mm) was not associated with MPA and VPA. Higher humidity was consistently related to lower MPA and VPA, and solar radiation was related to higher MPA and VPA. Day length showed no association with PA. As can be observed in Figure 1, temperature showed a significant curvilinear relationship with MPA and VPA (reflecting the linear and quadratic variables of temperature in Table 2). The temperature that corresponded with highest engagement in MPA and VPA was 22 and 20 degrees Celsius, respectively. When analyses were repeated for sedentary time, general results were equally strong but in opposite direction (see Supplemental Table 1 in Appendix 3). When MPA and VPA results were compared to light PA, differences were found regarding temperature (i.e. no decline in light PA observed at temperatures above 25 degrees Celsius), humidity (i.e. no relationship observed) and rainfall (i.e. 7.6-46.0 mm rainfall associated with more light PA) (see Supplemental Table 1 in Appendix 3).

Table 1: Distribution of physical activity and weather variables across the school terms

Daily level (*n*=4599 days of measurement)	School Term 1 (summer)	School Term 2 (autumn)	School Term 3 (winter)	School Term 4 (spring)
Number of children included (% from total)	238 (77.5%)	212 (69.1%)	269 (87.6%)	272 (88.6%)
Accelerometer weartime (daily minutes), mean (SD)	780.0 (212.3) *	807.0 (224.6) [1 4]	826.3 (214.9) [1]	814.7 (208.8) [1]
Sedentary time (daily minutes), mean (SD)	467.1 (174.6) [2 3]	492.2 (191.8) [1 4]	492.8 (181.3) [1 4]	473.8 (176.1) [3]
Light physical activity (daily minutes), mean (SD)	253.2 (70.8) [4]	249.5 (71.9) [3 4]	258.2 (66.4) [2 4]	267.7 (73.1) *
Moderate physical activity (daily minutes), mean (SD)	43.7 (21.0) [3 4]	45.9 (22.2) [3 4]	50.8 (20.6) [1 2]	51.8 (22.3) [1 2]
Vigorous physical activity (daily minutes), mean (SD)	16.7 (14.4) *	19.5 (15.2) *	25.1 (18.4) *	21.4 (16.0) *
Moderate physical activity (daily average in %), mean (SD)	5.8 (2.8) [3 4]	5.9 (2.9) [3 4]	6.4 (2.6) [1 2]	6.5 (2.8) [1 2]
Vigorous physical activity, (daily average in %), mean (SD)	2.2 (1.9) *	2.5 (2.1) [1 3]	3.2 (2.5) *	2.7 (2.0) [1 3]
Rainfall (number of days) (%)	*	*	*	*
No rainfall	591 (60.5)	446 (50.8)	532 (36.4)	846 (66.0)
0.01 – 7.8 mm per day	218 (22.3)	217 (24.7)	514 (35.2)	136 (10.6)
7.9 – 46.0 mm per day	168 (17.2)	215 (24.5)	416 (28.5)	300 (23.4)
Humidity (daily average in percentage), mean (SD)	60.0 (12.6) [2 3]	71.2 (13.0) *	67.2 (10.6) *	61.0 (12.3) [2 3]
Day length (total daily minutes), mean (SD)	761.8 (34.2) *	599 (20.3) *	651.3 (21.7) *	851.4 (18.7) *
Temperature (daily maximum in °C), mean (SD)	27.5 (5.2) *	16.6 (2.8) *	15.2 (2.9) *	22.6 (5.3) *
Solar Radiation exposure (daily total in MJ/m^2), mean (SD)	19.56 (7.23) *	6.99 (2.61) *	10.28 (3.61) *	21.74 (7.59) *

Differences between school terms for continuous variables were tested using Bonferroni-corrected analyses of variance and for categorical variables using chi-square tests : * statistically significant difference between term in column and all other school terms, [1] statistically significant difference between term in column and school term 1 (summer), [2] statistically significant difference between term in column and school term 2 (autumn), [3] statistically significant difference between term in column and school term 3 (winter), [4] statistically significant difference between term in column and school term 4 (spring).

Table 2: Relationship between weather elements and physical activity (*n*=4599 days, *n*=307 children)

	Moderate PA std. B (95%CI)	Vigorous PA std. B (95% CI)
	-2 restricted log likelihood = 10834	-2 restricted log likelihood = 10759
Rainfall (0.01–7.8 mm per day versus no rainfall)	**0.087 (0.029 to 0.145)**	**0.062 (0.005 to 0.119)**
Rainfall (7.9–46.0 mm per day versus no rainfall)	-0.065 (-0.152 to 0.022)	-0.007 (-0.093 to 0.078)
Humidity	-0.070 (-0.108 to 0.033)	**-0.085 (-0.122 to -0.048)**
Day length	-0.050 (-0.177 to 0.076)	-0.079 (-0.202 to 0.044)
Temperature	**0.378 (0.177 to 0.579)**	0.108 (-0.089 to 0.304)
Temperature squared	**-0.484 (-0.665 to -0.302)**	**-0.297 (-0.474 to -0.120)**
Solar Radiation exposure	**0.079 (0.037 to 0.121)**	**0.065 (0.024 to 0.106)**
Day type (weekday versus weekend day)	**0.438 (0.380 to 0.496)**	**0.333 (0.276 to 0.389)**
Gender (boys versus girls)	**0.523 (0.410 to 0.636)**	**0.531 (0.397 to 0.665)**
Age in years	**-0.118 (-0.178 to -0.058)**	-0.051 (-0.122 to 0.019)
Body Mass Index	0.026 (-0.026 to 0.079)	**-0.107 (-0.168 to -0.046)**

Table shows fixed effects (as standardized regression coefficients (std. B) with 95% confidence intervals (CI) from linear mixed models, with a random intercept for each child, and a repeated term for each child across each repeated observation, with autoregressive covariance structure. Bolded text indicates significant at $p<0.05$.

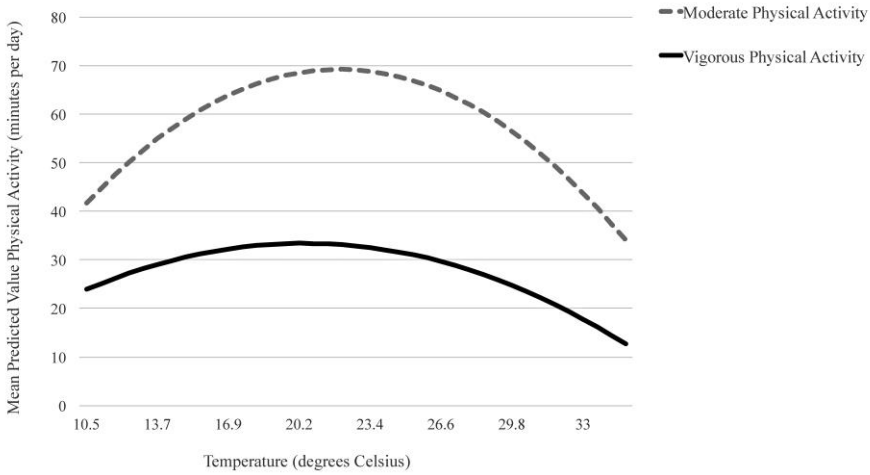


Figure 1: Relationship between Temperature and Physical Activity. Mean Unstandardized Predicted Values of Moderate and Vigorous Physical Activity were adjusted for rainfall, humidity, day length, day type, gender, age, and BMI. For Moderate Physical Activity p-value temperature < 0.01; p-value temperature^2 < 0.01. For Vigorous Physical Activity p-value temperature = < 0.86; p-value temperature^2 < 0.01.

Moderation across weather elements, and between socio-demographics and day type

There was statistically significant moderation for solar radiation in the relationship between temperature and MPA and VPA (improvement of the model by including interaction-terms $p < 0.01$ for both MPA and VPA, likelihood ratio test with 2 *df*). This means that the previously computed temperature that corresponded to highest PA, depends on the level of solar radiation. We dichotomized solar radiation to graphically demonstrate this. It should be noted that during days with low solar radiation, maximum temperatures only reached 29.1 degrees Celsius, while in days with high solar radiation, temperatures were recorded up to 39.1 degrees Celsius (see Figures SDC2 and SDC3 in Appendix 3). Consequently, temperature had a smaller influence on children's MPA and VPA during days with lower solar radiation; while temperatures (above 25 degrees Celsius) were strongly associated with lower MPA levels during days with high solar radiation (see Figure SDC2 and SDC3 in Appendix 3). This can also be deducted from the negative interaction-term solar*temperature, while the interaction-term of the quadratic term solar*temperature squared was positive (see Supplemental Table 4 in Appendix 3)

In addition to the interaction described above, moderation was also found between day type and temperature in the relationship with VPA (see Supplemental Table 5 in Appendix 3; moderation of weather elements and day type in relationship between weather elements and vigorous PA). We found a strong curvilinear relationship between temperature and VPA during weekdays; while during weekends temperature was linearly related with lower VPA (see Figure SDC6 in Appendix 3). We found no indication for moderation by gender, age, and BMI.

Discussion

This study first investigated associations between weather elements and children's daily PA patterns, and secondly the moderating effects of day of the week (weekdays vs. weekend days) and gender, age and BMI on the relationship between these weather elements and PA, using an extensive longitudinal design containing measurements across four seasons. Temperature and day type (weekdays versus weekends) were the strongest variables explaining MPA and VPA; followed by equal contributions from solar radiation and humidity. Temperature showed a curvilinear relationship, with highest engagement in MPA and VPA levels occurring at 22 and 20 degrees Celsius, respectively. Relative humidity was consistently related to lower MPA and VPA, and solar radiation was consistently related to higher MPA and VPA. Little rainfall (0.1–7.8mm) was associated with higher MPA compared to no rainfall, but no association was found for heavier rainfall (7.9-46.0mm). When compared against sedentary time, results were equally strong but in opposite direction, suggesting that the increments observed in MPA and VPA were accompanied with a similar decrease in sedentary time.

The curvilinear relationship found between temperature and MPA and VPA was highly comparable with results from the study by Lewis et al. (21), which also reported an optimal temperature around 20-25 °C related to PA among children in Australia and Canada. For light PA however, we did not observe this typical curvilinear relationship. In addition, our study found that there was a notable curvilinear relationship between temperature and VPA during weekdays. During weekends, we found no evidence for such a curvilinear relationship, but still, higher temperatures were related to lower VPA. Lewis et al. (21) reported that the influence of weather was stronger on weekdays; while Duncan et al. (9) and Atkin et al. (3) in contrast reported that this was generally true for weekend days. Inconsistency regarding these findings may be explained by the possibility that on weekends with temperatures above 20 °C, more free-time may have been spent in water-related activities which likely resulted in misclassification of actual PA behavior as children were instructed to not wear the accelerometer during water-activities (21). Another explanation may be that the scheduling of structured PA (e.g. team sports) may have resulted in fewer PA opportunities in warmer periods of the year (26). However, by allowing for an individualized intercept and repeated measures for each participant across each day of measurement, it is more conceivable that daily changes in temperature influenced PA in our study, rather than the role of potential changes in structured PA.

We found that solar radiation was consistently associated with higher MPA and VPA. Duncan et al. also examined solar exposure in their New Zealand study (9), but no associations were found with PA (9). This may be due to different definitions of solar radiation, as the present study defined solar radiation as the daily total in MJ/m^2, while Duncan et al. (9) defined solar radiation as the duration of absent cloud cover. As the former provides more valid information about the actual intensity of solar radiation, this measure may be more likely to be related with PA behavior. In addition, although suggested by Duncan et al. (9), this is the first study that has investigated moderation

mechanisms between weather elements and their association with PA. Such moderation was found for temperature and solar radiation. Apart from the potential influence of water-related activities, sun protection policies may also have influenced children's PA particularly during the warmer months. At higher intensities of solar radiation (UV-levels ≥ 3), SunSmart protection measures in Australia encourage children to stay in the shade and wear protective clothing (e.g. hats and long sleeve tops) during periods of the day with extreme UV-levels. This may have hindered children's participation in outdoor PA (18), and thus may have contributed to the moderation between temperature and day type in the relationship with VPA (see Figure SDC6 in Appendix 3). Similar school policies regarding promotion of indoor PA during wet weather conditions (14), may also be required during periods of the day with extreme UV-levels.

While we found consistent associations between relative humidity and lower PA, Lewis et al. (21) found no such associations with MVPA (21). Humidity may influence PA in a way that the sensation of heat (at higher temperatures) depends on relative humidity (27, 28), which suggests a moderating mechanism between temperature and humidity in the relationship with PA. However no evidence for interaction was found in our study. Therefore regardless of temperature, PA may be more exhausting and uncomfortable for children in higher relative humidity, and therefore it may be best to encourage indoor activities on days of high humidity. Moreover, no associations were found between humidity and light PA. Similar to temperatures above 25 degrees Celsius, increments in humidity are especially related to declines in PA at high intensity. This may mean that these meteorological circumstances may discourage and/or limit children from performing MPA/VPA because of discomfort and/or increased fatigue.
Except for positive associations in the Canadian sample examined by Lewis et al. (21), five studies reported negative associations between rainfall and PA (9, 12, 21). In the current study however, results regarding rainfall were mixed. Interestingly, only Duncan et al. (9) and Harrison et al. (14, 15) categorized of rainfall due to its skewed distribution (9). Unlike the study of Duncan et al. (9) but in line with the studies of Harrison (14, 15), categorization of rainfall in our study was based on days with no rainfall, and subsequently split into two categories of similar size. When we applied the same category-thresholds as Duncan et al. (9) however, results remained unchanged. A potential explanation for the mixed rainfall findings in our study may be that children performed PA between rain showers, or inside during rainfall. As we had no data on the rainfall characteristics (e.g. intensity, duration or timing of rainfall) or indoor/outdoor timing, we cannot speculate how much influence rainfall had on children's daily PA levels. In addition, future studies that have access to wind speed data may also investigate whether average daily wind speed (or in a moderation mechanism with rainfall) influence children's PA behavior. Interestingly, one study reported clear declines in lunchtime and after-school PA with increasing rainfall in 9-11 year-old children, but no associations were found for 13-14 year-old children (15). Unfortunately our daily rainfall data and limited age range do not allow direct comparison with these findings (15). Future studies are encouraged to include rainfall characteristics and indoor/outdoor time in their analyses,

as preliminary results indicated that children were most active in schools with policies to provide opportunities for active indoor activities during wet weather (14).

Given our longitudinal design across four school terms, substantial variations in day length were recorded in our study; however, no associations between day length and PA were observed. Unlike the study of Goodman (12), we entered day length as a continuous variable in our models. When we computed tertiles based on equal frequency distributions however, some small differences in MPA were found but results were inconsistent (data not shown). Initial multi-collinearity statistics provided indications for potential multicollinearity between day length, temperature and solar radiation. Hence, we investigated this in sensitivity analyses. For example, removing temperature or solar radiation from our models led to significant decrease in model fit ($p < 0.05$ for MPA and VPA), while the association between day length and MPA remained unchanged (data not shown). Based on these sensitivity analyses, we decided to retain day length in the models as we deemed multicollinearity not to have significantly influenced our results. However, in line with the present study, previous studies reported that associations between day length and PA were only strong during the late afternoon and early evening (12), and only small increases in overall daily PA were shown between days with large differences in sunset times (i.e. before 5 PM versus after 9 PM) (11). Consequently, day length may independently increase PA in late afternoons and evenings, but associations between day length and overall PA across the whole day seem to be weak (11).
According to the results of Goodman et al., this may be due to an increase in light PA during late afternoon or early evenings (12). In addition, it is possible that day length might have less influence on PA performed as part of organized sports versus discretionary PA (e.g. sports facilities may be more likely to be lit than playgrounds). Future studies are encouraged to further examine these distinct PA patterns.

Strengths and weaknesses

To our knowledge this is the first study to use a longitudinal design to investigate the influence of weather elements on children's intra-individual PA patterns. The repeated measurements distributed across four school terms within one year ensured variation in weather elements and are representative of yearly PA patterns among Australian children.
The present study's approach of PA patterns within individuals is different from earlier studies. These studies typically analyzed between-individual differences, aggregating PA over days. Within-individual analyses, such as in our study, are better able to characterize day-to-day variation in children, helping us to understand PA patterns in children.

In our study, the lowest average temperature recorded was 10.7 degrees Celsius. Therefore, these findings may not be generalised to countries with lower winter temperatures. In addition, weather elements also show within-day variability (e.g. short periods of heavy rainfall may have a different influence on PA than prolonged light rainfall) (12). Future studies are encouraged to also analyze within-day variability of weather elements in relation to PA patterns, particularly in regions where the weather is

highly variable across the day. Although we accounted for differences between each day of measurement within children (as a repeated term) and thus also for potential differences in sports participation across school terms, the influence of weather elements may still be underestimated by indoor sports participation. Related to this, future studies may also investigate whether the relationship between weather elements and PA is consistent over time. Underestimation of our results may also stem from children's cycling behavior, which is not well captured by hip-worn accelerometers, but may vary according to weather elements (23). One could also argue that despite this study controlling for weartime, our results may be influenced by differences in weartime across school terms. For example, especially in summer, weartime (and VPA) was lower compared to other school terms. However, sensitivity analyses revealed that no notable changes were detected when models were repeated for low versus high weartime (data not shown). Finally, we were unable to account for the possibility that water-based PA may have influenced our results in warmer periods of the year. The use of extensive PA diaries or combined Global Positioning System (GPS) and accelerometer methodology in future studies may be able to recognize specific types of PA and their context.

Implications

This study has important implications for future study methodology. As weather influences cannot be controlled, knowledge of its influence on individual PA patterns may inform the design, analysis and interpretation of future studies; especially when investigating PA across diverse meteorological settings and with long follow-up periods. Also, future interventions should not only account for inter-individual-, but also for intra-individual changes of weather elements in their analyses. This study also has implications for countries that often experience high temperatures (>25 degrees Celsius). As this study showed substantially lower levels of PA at these high temperatures, researchers are encouraged to investigate mechanisms behind this inactivity (e.g. parents/schools keeping children inside or children's own inclination to be less active). Policy makers in these countries are advised to provide infrastructure to promote and support appropriate PA in these temperatures, while being cautious about adverse health effects of high solar radiation and overheating.

Acknowledgments

The authors gratefully acknowledge the contribution of all participating children and project staff. We also acknowledge Eoin O'Connell for the development of the customized Excel macro. The authors declare that they have no competing interests. Study results and methodology are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. Results of the present study do not constitute endorsement by ACSM.

Funding

TR was supported by the University Fund Limburg (Grant 15.021). The PHASE Study and NDR were supported by an Australian Research Council Discovery Early Career Researcher Award (DE120101173). JS is supported by a National Health and Medical Research Council Principal Research Fellowship (APP1026216). AT is supported by a Future Leader Fellowship from the National Heart Foundation of Australia (Award ID 100046). JV is supported by a National Health and Medical Research Council Early Career Fellowship (ID 1053426).

References

1 Australian Bureau of Statistics Website. Census of Population and Housing: Socio-Economic Indexes for Areas (SEIFA), Australia; (cited 2016 May 1). Available from: http://www.abs.gov.au/ausstats/abs.nsf/mf/2033.0.55.001.

2 Australian Government’s Bureau of Meteorology Website (Internet). Australian Government’s Bureau of Meteorology; (cited 2015 Nov 20). Available from: http://www.bom.gov.au/.

3 Atkin AJ, Sharp SJ, Harrison F, Brage S, van Sluijs E. Seasonal Variation in Children's Physical Activity and Sedentary Time. Medicine & Science in Sports & Exercise. 2016;48(3):449-56.

4 Cain KL, Sallis JF, Conway TL, Van Dyck D, Calhoon L. Using accelerometers in youth physical activity studies: a review of methods. Journal of Physical Activity and Health. 2013;10(3):437-50.

5 Carson V, Spence JC. Seasonal variation in physical activity among children and adolescents: a review. Pediatric Exercise Science. 2010;22(1):81.

6 Chan CB, Ryan DA. Assessing the effects of weather conditions on physical activity participation using objective measures. International Journal Environmental Research and Public Health. 2009;6(10):2639-54.

7 Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. British Medical Journal. 2000;320(7244):1240.

8 Deforche BI, De Bourdeaudhuij IM, Tanghe AP. Attitude toward physical activity in normal-weight, overweight and obese adolescents. Journal of Adolescent Health. 2006;38(5):560-8.

9 Duncan JS, Hopkins WG, Schofield G, Duncan EK. Effects of weather on pedometer-determined physical activity in children. Medicine & Science in Sports & Exercise. 2008;40(8):1432-8.

10 Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. Medicine & Science in Sports & Exercise. 2005;11(Sl):523-30.

11 Goodman A, Page AS, Cooper AR. Daylight saving time as a potential public health intervention: an observational study of evening daylight and objectively-measured physical activity among 23,000 children from 9 countries. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1):84.

12 Goodman A, Paskins J, Mackett R. Day length and weather effects on children's physical activity and participation in play, sports, and active travel. Journal of Physical Activity and Health. 2012;9(8):1105.
13 Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U. Global physical activity levels: surveillance progress, pitfalls, and prospects. The Lancet. 2012;380(9838):247-57.
14 Harrison F, Jones AP, Bentham G, van Sluijs EM, Cassidy A, Griffin SJ. The impact of rainfall and school break time policies on physical activity in 9-10 year old British children: a repeated measures study. Int J Behav Nutr Phys Act. 2011;8(1):1.
15 Harrison F, Van Sluijs EM, Corder K, Ekelund U, Jones A. The changing relationship between rainfall and children's physical activity in spring and summer: a longitudinal study. International Journal of Behavioral Nutrition and Physical Activity. 2015;12(1):1.
16 Janssen I, LeBlanc AG. Review Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. International Journal of Behavioral Nutrition and Physical Activity. 2010;7(40):1-16.
17 Jones RA, Hinkley T, Okely AD, Salmon J. Tracking physical activity and sedentary behavior in childhood: a systematic review. American Journal of Preventive Medicine. 2013;44(6):651-8.
18 Jones SB, Beckmann K, Rayner J. Australian primary schools' sun protection policy and practice: evaluating the impact of the National SunSmart Schools Program. Health Promotion Journal of Australia. 2008;19(2):86.
19 Kolle E, Steene-Johannessen J, Andersen LB, Anderssen SA. Seasonal variation in objectively assessed physical activity among children and adolescents in Norway: a cross-sectional study. International Journal of Behavioral Nutrition and Physical Activity. 2009;6(1):36.
20 Kutner MH, Nachtsheim C, Neter J. Applied linear regression models. 4th ed. Boston, MA: McGraw-Hill Education; 2004.
21 Lewis L, Maher C, Belanger K, Tremblay M, Chaput J, Olds T. At the Mercy of the Gods: Associations Between Weather, Physical Activity and Sedentary Time in Children. Pediatric Exercise Science. 2016;28(1):152-63.
22 Martin S, Carlson S. Barriers to children walking to or from school. Morbidity and Mortality Weekly Report. 2005;54(38):949-52.
23 Martin SL, Lee SM, Lowry R. National prevalence and correlates of walking and bicycling to school. American Journal of Preventive Medicine. 2007;33(2):98-105.
24 Mattocks C, Leary S, Ness A, Deere K, Saunders J, Kirkby J, et al. Intraindividual variation of objectively measured physical activity in children. Medicine & Science in Sports & Exercise. 2007;39(4):622-9.
25 Rich C, Griffiths LJ, Dezateux C. Seasonal variation in accelerometer-determined sedentary behaviour and physical activity in children: a review. International Journal of Behavioral Nutrition and Physical Activity. 2012;9(1):49.

26 Ridgers ND, Salmon J, Timperio A. Too hot to move? Objectively assessed seasonal changes in Australian children's physical activity. International Journal of Behavioral Nutrition and Physical Activity. 2015;12(1):77.
27 Rothfusz LP. The heat index equation (or, more than you ever wanted to know about heat index). Fort Worth (TX): National Oceanic and Atmospheric Administration, National Weather Service, Office of Meteorology; 1990.
28 Steadman RG. The assessment of sultriness. Part I: A temperature-humidity index based on human physiology and clothing science. Journal of Applied Meteorology. 1979;18(7):861-73.
29 Strong WB, Malina RM, Blimkie CJ, Daniels SR, Dishman RK, Gutin B, et al. Evidence based physical activity for school-age youth. Journal of Pediatrics. 2005;146(6):732-7.
30 Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut-points for predicting activity intensity in youth. Medicine & Science in Sports & Exercise. 2011;43(7):1360-8

CHAPTER 7

Playability of school-environments and after-school physical activity among 8–11 year-old children: specificity of time and place

This chapter has been published as:

Remmers T. Van Kann DH. Thijs C. de Vries SI, Kremers SP. Playability of school-environments and after-school physical activity among 8–11 year-old children: specificity of time and place. International Journal of Behavioral Nutrition and Physical Activity. 2017;13(1):82.

Abstract

Introduction: Physical Activity (PA) occurs in several behavioral domains (e.g. sports, active transport), and is affected by distinct environmental factors. By filtering objective PA using children's school schedules, daily PA can be separated into more conceptually meaningful domains. We used an ecological design to investigate associations between "playability" of 21 school-environments and children's objectively measured after-school PA. We also examined to what extent distinct time-periods after-school and the distance from children's residence to their school influenced this association.
Methods: PA was measured in 587 8-11 year-old children by accelerometers, and separated in four two-hour time-periods after-school. For each school-environment, standardized playability-scores were calculated based on standardized audits within 800 meters network buffers around each school. Schools and children's residences were geocoded, and we classified each child to be residing in 400, 800, 1600, or >1600 meters crow-fly buffers from their school. The influence of network-distance buffers was also examined using the same approach.
Results: Playability was associated with light PA and moderate-to-vigorous PA after-school, especially in the time-period directly after-school and among children who lived within 800 meters from their school. Playability explained approximately 30% of the after-school PA variance between schools. Greater distance from children's residence to their school weakened the association between playability of the school-environments and after-school PA.
***Conclusions*:** This study demonstrated that relationships between the conceptually matched physical environment and PA can be revealed and made plausible with increasing specificity in time and distance.

Introduction

The short- and long-term benefits of physical activity (PA) in children are well known. The role of attributes of the physical environment in regulation of children's PA behavior has been given increasing attention in recent years, but results so far have been mixed (1). Although the use of objective measurements is preferred in PA-related research involving children (e.g. by accelerometers), investigating relationships between PA and the physical environment using objective measurements proves to be challenging (2).

A first challenge is assessing children's exposure to detailed elements of the physical environment. Researchers in the disciplines of health sciences, urban planning, and leisure studies all contribute to the development of measurements assessing these environmental elements (3). In general, three types of measurements can be identified; self-administered surveys, systematically completed audits, and GIS-based measures (4). In terms of objective measurements, GIS-based measures may currently be more suitable for assessing design-related features of neighborhoods on a larger geographic scale. Audits, in turn, may be more suitable to assess qualities of environmental elements in smaller-scaled environmental settings (4, 5). In studies investigating PA in children, audits may thus be favorable in detecting (quality of) small-scaled environmental opportunities that may potentially influence leisure time PA (e.g. attractiveness and quality of public spaces or playgrounds). Recently, an instrument assessing detailed playground characteristics using systematic in-person audits of environments have been introduced as a "playability index" (6). This index stems from the Environmental Assessment of Public Recreational Spaces (EAPRS) (7) and assesses qualities of playground-features such as facilities, aesthetics, proximity, and accessibility.

A second challenge when investigating relationships between PA and the physical environment stems from the paradigm that PA occurs in several conceptual domains (i.e. leisure, school, transport and home) (8-10). Investigating associations between the environment and overall PA may lead to inconsistencies, as different PA domains are regulated by distinct environmental factors (4). An example of domain-specificity relates to children's school schedule, which largely limits their spatial freedom- and thus environmental exposure during weekdays. Separately investigating after-school PA (ASPA) helps to increase our understanding children's context-specific PA and its environmental attributes (2, 9, 11-13). Studies using subjective measures of ASPA generally reported that boys seemed to be more active after school than girls (14, 15) and suggested a negative influence of technology-related sedentary activities on ASPA (15, 16). The studies that used objective measures generally indicated that ASPA contributed considerably to total PA, that boys were indeed more active after school (17-27). More specifically, one study reported that children do not compensate inactive days at school by increasing ASPA on a weekly basis (28). Three studies reported on relationships between ASPA and objectively audited features of the environment (22, 24, 26). Results generally revealed that time outside resulted in 2-3 fold higher ASPA (26), but no associations were found between the number and proximity of PA- facilities / public open spaces / playgrounds in the

environment (and their specific features such as lightning and trees) and ASPA in children (22, 24). However in the audits of the studies above, no information was recorded about the quality of these PA-facilities (e.g. attractiveness, maintenance status or age-appropriateness). This may be important, as other factors than actual distance to public open spaces may determine the use of public open spaces or playgrounds (24, 29).

An advantage of investigating ASPA is that when using exact school bell-times, relationships between ASPA and attributes of the school-environment can be investigated with an equal starting-point; both regarding time-opportunities and geographical location for all children attending the same school. To even further improve our understanding of this association, the ASPA time-period may be separated into even more precise time-segments after school bell-times. For example, by theory, children are all optimally exposed to the school-environment directly after school ends (i.e. bell times) but to a lesser extent later in the afternoon. Greater distances of a child's residence to the school-environment may attenuate relationships between playability and ASPA, because children living further away may be more likely to engage in ASPA at places outside the school-environment under study.

Consequently, the present study used an ecological approach to investigate the association between environmental playability and objectively measured ASPA of 8-11 year-old children, using audits of school-environments. In addition, we aimed to demonstrate that with increasing specificity in time and distance, relationships between school-environments and ASPA can be revealed and made plausible.

Methods

This investigation was embedded in a prospective study in the Southeast part of the Netherlands, focusing on environmental attributes and PA in Dutch primary school children. The design and protocol are described in detail elsewhere (30). After obtaining parental informed consent, 815 sixth and seventh grade primary-school pupils from 21 schools participated in PA measurements and questionnaires for both one of the parents and child. Data collection took place between the 26th of September and the 1st of December 2012 and analyses were performed in 2015. The Medical Ethics Committee of the Maastricht University Medical Center approved this study (reference number METC 12-4-077).

Measurements

After-School Physical Activity

ASPA was measured using ActiGraph GT3X+ accelerometers (30Hz) for five consecutive days (ActiGraph, Pensacola, FL), defining non-wear periods according to 60 minutes of consecutive zero's according to Troiano's criteria (31). Activity intensity classification was based on Evenson's cutpoints (32). Participants were instructed to only remove the

accelerometer in water-related activities, so we explicitly instructed them to keep wearing them during sports-activities. We excluded measurements containing less than 250 minutes per day of registration time, for at least two weekdays. Although studies investigating whole-day PA patterns usually apply more stringent criteria for these registration times (33), we were only interested in a smaller part of the daily PA pattern and therefore required less registration time. Weekend days and Wednesdays (because of a shortened school-schedule) were excluded. Accelerometry was aggregated to hourly averages, for each day of measurement. Using weartime-filters, ASPA was filtered from total PA registration time, based on exact school's bell times. ASPA was then separated in four two-hour time periods: 1) directly after-school–16:00, 2) 16:00-18:00, 3) 18:00-20:00, and 4) 20:00–22:00. All schools ended between 14:45 and 15:30. To ensure that these time-periods represented hourly patterns, and are thus not influenced by spurious PA-spikes in children with limited period-specific weartimes, we only included accelerometer data that consisted of at least 50% of the period-specific registration time (i.e. at least one hour in a two-hour registration period) (26, 27, 34). For the first time period, we tailored the percentage of period-specific weartime based on individual school bell-times.

Based on data from the Royal Dutch Meteorological Institute (KNMI), we also identified meteorological circumstances (i.e. average temperature, average duration of rainfall, and average duration of sunshine per day) during measurement-days.

Playability

Playability of the school-environments was assessed by two trained researchers using the SPACE observation instrument (35, 36), within an 800 meters radius from each school, while acknowledging natural barriers such as highways or canals. This 54-item instrument audits PA friendliness of neighborhoods and assesses characteristics such as residential density, playground characteristics, and traffic intensity, based on the Neighborhood Environment Walkability Scale but modified to reflect the Dutch environmental context (37, 38). Inter-rater agreement between the two researchers who audited school-environments was acceptable (Kappa = 0.73). Playability was operationalized by first extracting items representing characteristics of playgrounds (excluding schoolyards) within the 800 meters crow-fly surface areas. Extracted were the playground's size in squared meters, accessibility (safely accessible versus not-safely accessible), opening hours (unlimited versus limited), maintenance-status (poor versus good), number of facilities (e.g. climbing-facilities and soccer goals), and age-appropriateness of these facilities for 8-11 year-old children (none, partly, and fully age-appropriate). Each individual playground-characteristic was summed and standardized based on equal weights, to reflect one standardized score for each individual playground. Subsequently, these scores were aggregated to a playability index-score for each school-environment.

Distance from children's residence to their school

Since in the Netherlands a limited number of primary schools generally cover a small residential area, parent's decisions regarding the school of their children is often based on the (close) distance from their residence (39, 40). Because of this vicinity to their school,

children from the same school share large parts of their physical environment (Figure 1). Therefore, these shared school-environments provide unique opportunities for investigating relationships between ASPA and the physical environment. Location of schools and respondent's residences were geocoded, and we computed a 400, 800 and 1600 meters crow-fly buffer around each school using ArcGIS (ESRI ArcGis Desktop 10.2. Redlands, CA). We subsequently classified each residence to be located 1) inside the 400 meters buffer-area, 2) outside 400, but inside 800 meters, 3) outside 800, but inside 1600 meters, 4) outside the 1600 meters buffer area. As crow-fly distances may be misleading because of barriers in the environment (e.g. highways or canals), we also computed network-distance as the shortest network distance in meters via the street network from each child's residence to their school using Google Maps (GoogleMaps, 2015), and recoded distances in four categories. In order to keep sample sizes within categories comparable with the crow-fly distance, we based categorization on equal frequency distributions.

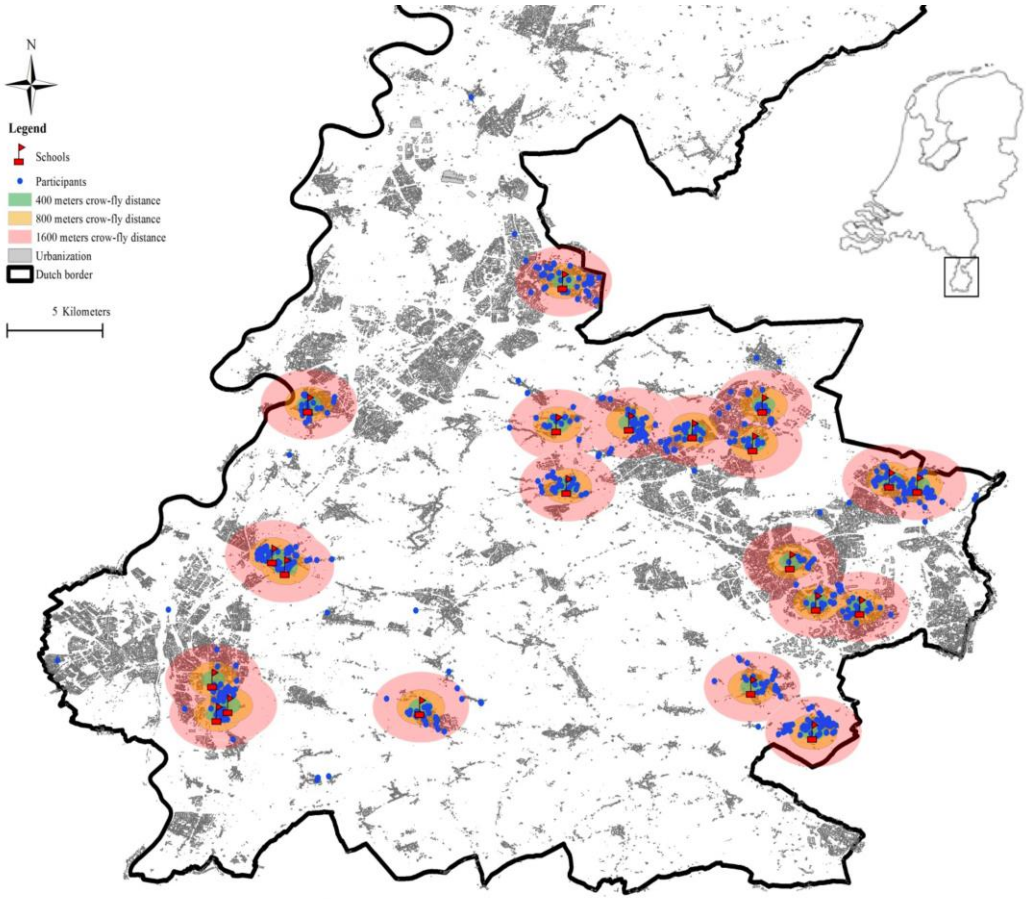


Figure 1: Geographical location of included schools and participants

Statistical analyses

Our analyses were performed using SPSS 20.0 for Windows (IBM SPSS Inc., Armonk, NY), and $p<0.05$ indicated statistical significance. Our dependent variable was the ASPA performed in light and moderate to vigorous intensity for each hourly time-interval of measurement. Our primary independent variable was the combined playability index of the different school-environments. We first described the percentages of light PA (LPA) and moderate-to-vigorous PA (MVPA) across four two-hour time-periods after school, and across four distance-buffers from schools using univariate analyses of variance (Table 1). We performed multilevel linear mixed models in order to account for the time-dependent structure of the data. We specified a random intercept and slope for the hourly time-intervals, nested within the specific dates at which a respondent's accelerometry commenced. Analyses were also adjusted for hourly weartime, average daily temperature, daily duration of rainfall, and daily duration of sunshine per day. We evaluated whether age and gender moderated the association between playability and ASPA, but as we did not find moderation, we only adjusted for age and gender.

To investigate the influence of the four time-periods and distance-categories on the relationship between ASPA and playability, we entered the appropriate interaction terms in our linear mixed models. Using dummy-coded interaction-terms between distance-categories and the playability index-score, we were able to estimate main effects of playability for each of the two-hour time periods, while still acknowledging the time-dependent structure with the random intercept and slope. Distance-categories were both conceptualized as crow-fly and network-distances. Finally, we also repeated our analyses now stratifying for the time-periods and distance-categories simultaneously to investigate their interactive influence (Table 4)

Results

In total, 587 children (74.2%) provided valid ASPA measurements, for two (44.8%) and three (55.2%) valid weekdays, respectively. The 280 participating boys and 307 girls were aged 10.2 years on average (range 8 to 11 years) (Table 1). Across all time-periods, 27.9% of the time after-school was spent in LPA, which accumulated to 103.4 minutes per day (SD=23.9). MVPA accounted for 7.7% of the after-school time, accumulating to 28.4 minutes per day (SD=14.6). Daily percentages of LPA declined across the four time-periods, while MVPA slightly declined after 16:00, but increased again after 18:00. Daily percentages of LPA and MVPA were comparable across the distance-categories (no statistically significant differences in analysis of variance, data not shown).

Table 1: Descriptive statistics of the study population

Individual level (*n*=587)	
Age; mean years (sd) (missing *n* = 10)	10.2 (0.7)
Gender; *n* boys (%)	280 (47.7)
Ethnicity *n* Dutch (%) (missing *n* = 9)	490 (84.4)
Crow-fly distance from home to school; *n* (%)	
within 400 meters	187 (31.9)
within 800 meters	225 (38.3)
within 1600 meters	119 (20.3)
outside 1600 meters	56 (9.5)
Network distance from home to school; *n* (%)	
distance ≤ 499 meters	138 (23.5)
distance 500 – 799 meters	137 (23.3)
distance 800 – 1199 meters	171 (29.1)
distance ≥ 1200 meters	141 (24.0)
Light PA by time of the day; mean % of time per day (sd)	27.9 (6.6)
end of the school day – 16:00 hours; mean % (sd) (*n*= 539)	35.3 (8.8)
16:00 – 18:00 hours; mean % (sd) (*n*= 586)	29.2 (8.2)
18:00 – 20:00 hours; mean % (sd) (*n*= 585)	27.5 (7.7)
20:00 – 22:00 hours; mean % (sd) (*n*= 326)	20.8 (9.5)
MVPA by time of the day; mean % of time per day (sd)	7.7 (4.0)
end of the school day – 16:00 hours; mean % (sd) (*n*= 539)	10.4 (6.2)
16:00 – 18:00 hours; mean % (sd) (*n*= 586)	6.8 (4.8)
18:00 – 20:00 hours; mean % (sd) (*n*= 585)	9.2 (7.5)
20:00 – 22:00 hours; mean % (sd) (*n*= 326)	4.8 (6.2)
Light PA by crow-fly distance; mean % of time per day (sd)	27.9 (6.6)
within 400 meters (*n*= 187)	28.2 (7.0)
within 800 meters (*n*= 225)	28.0 (6.4)
within 1600 meters (*n*= 119)	27.9 (6.3)
outside 1600 meters (*n*= 56)	27.3 (6.5)
MVPA by crow-fly distance; mean % of time per day (sd)	7.7 (4.0)
within 400 meters (*n*= 187)	7.9 (4.1)
within 800 meters (*n*= 225)	7.9 (4.1)
within 1600 meters (*n*= 119)	7.4 (4.0)
outside 1600 meters (*n*= 56)	7.3 (3.8)

Playability and after-school Physical Activity by time-period

Children who attended schools in areas with higher playability scores, generally showed significantly higher LPA and MVPA in the first two time-periods (i.e. between the end of the school day and 18:00) (Table 2). By contrast, in the subsequent time-periods, the association between playability and ASPA attenuated. Only the relatively small amount of time performed in light intensity between 20:00 and 22:00 unexpectedly showed a statistical significant relationship with playability.

Playability and after-school Physical Activity by distance-categories

Only if children lived within 400 meters from their school, after school LPA was positively associated with playability (Table 3). When children lived beyond 400 meters from their school, associations attenuated and were no longer statistically significant. For after school MVPA, the attenuating influence of distance from home to school was detectable when exceeding the 800m crow-fly or network-distance.

Table 2: Associations between playability and after-school physical activity intensities by time of the day

	% Light PA	% MVPA
Time of the day		
End of the school day – 16:00 hours (*n*= 539)	**0.043 (0.026 to 0.060)**	**0.029 (0.008 to 0.048)**
16:00 – 18:00 hours (*n*= 586)	**0.018 (0.002 to 0.034)**	**0.028 (0.012 to 0.045)**
18:00 – 20:00 hours (*n*= 585)	0.001 (-0.015 to 0.018)	-0.007 (-0.024 to 0.010)
20:00 – 22:00 hours (*n*= 326)	**0.052 (0.032 to 0.072)**	0.016 (-0.005 to 0.038)

Standardized beta's (with 95% confidence intervals in brackets) from linear mixed model analyses with a random intercept and slope over time (one-hour periods), nested within the dates at which measurement commenced. Results were adjusted for age, gender, average temperature, average duration of rainfall, and average duration of sunshine per day. Bold number represents statistical significance at $p<0.05$.

To examine the interactive influence of time and distance, analyses of time-periods were stratified for distance-categories from home to school (Table 4). The results of these stratified analyses were generally in line with the results described above. Regarding LPA, the attenuating influence of time-periods and distance-categories was comparable to the results Table 2 and 3, except for the distance greater than 1600 meters and time-period after 20:00 hours. Regarding MVPA, attenuating influences of time and distance were also comparable with Table 2 and 3, but in some instances revealed deeper insights. For example, ASPA after 16:00 hours (i.e. second time-period) was only associated with playability in children that lived within 400 meters from their school. When these analyses were repeated using network-distance, similar attenuating influences of time and distance were found (Table S1 in publication).

Table 3: Associations between playability and after-school physical activity, stratified by distance from children's residence to school

% Light PA				
Crow-fly distance from children's residence to school	< 400 meters	400-800 meters	800 - 1600 meters	outside 1600 meters
	0.039 (0.001 to 0.067)	0.018 (-0.007 to 0.042)	0.014 (-0.015 to 0.044)	0.007 (-0.039 to 0.053)
Network-distance from children's residence to school	≤ 499 meters	500 – 799 meters	800 – 1199 meters	≥ 1200 meters
	0.040 (0.007 to 0.071)	0.020 (-0.011 to 0.052)	0.023 (-0.004 to 0.049)	0.004 (-0.026 to 0.034)
% MVPA				
Crow-fly distance from children's residence to school	within 400 meters	within 800 meters	within 1600 meters	outside 1600+ meters
	0.026 (0.004 to 0.049)	**0.038 (0.018 to 0.057)**	0.018 (-0.006 to 0.041)	-0.005 (-0.042 to 0.031)
Network-distance from children's residence to school	≤ 499 meters	500 – 799 meters	800 – 1199 meters	≥ 1200 meters
	0.027 (0.002 to 0.052)	**0.046 (0.021 to 0.071)**	0.020 (-0.001 to 0.041)	0.011 (-0.013 to 0.035)

Standardized beta's (with 95% confidence intervals in brackets) from linear mixed model analyses with a random intercept and slope over time (one-hour periods), nested within the dates at which measurement commenced. Results were adjusted for age, gender, average temperature, average duration of rainfall, and average duration of sunshine per day. Bold number represents statistical significance at $p<0.05$.

Table 4: Associations between playability and after-school physical activity, stratified for time of the day and crow-fly distance from children's residence to school

	% Light PA			
Time of the day	within 400 meters	within 800 meters	within 1600 meters	outside 1600+ meters
End of the school day – 16:00 hours (*n*= 539)	**0.065 (0.032 to 0.100)**	**0.046 (0.015 to 0.074)**	**0.045 (0.009 to 0.080)**	0.001 (-0.052 to 0.054)
16:00 – 18:00 hours (*n*= 586)	0.027 (-0.004 to 0.058)	0.013 (-0.012 to 0.039)	0.031 (-0.0001 to 0.062)	0.009 (-0.041 to 0.059)
18:00 – 20:00 hours (*n*= 585)	0.024 (-0.008 to 0.057)	0.014 (-0.013 to 0.041)	-0.022 (-0.055 to 0.010)	-0.021 (-0.074 to 0.032)
20:00 – 22:00 hours (*n*= 326)	**0.051 (0.012 to 0.090)**	**0.061 (0.028 to 0.093)**	**0.043 (0.004 to 0.081)**	**0.075 (0.011 0.140)**
	% MVPA			
	within 400 meters	within 800 meters	within 1600 meters	outside 1600+ meters
End of the school day – 16:00 hours (*n*= 539)	**0.047 (0.010 to 0.083)**	**0.046 (0.012 to 0.080)**	-0.010 (-0.051 to 0.031)	0.006 (-0.053 to 0.065)
16:00 – 18:00 hours (*n*= 586)	**0.042 (0.010 to 0.074)**	0.023 (-0.005 to 0.050)	0.034 (-0.0003 to 0.068)	-0.006 (-0.057 to 0.046)
18:00 – 20:00 hours (*n*= 585)	0.017 (-0.016 to 0.050)	0.008 (-0.020 to 0.037)	-0.027 (-0.063 to 0.008)	**-0.088 (-0.141 to -0.034)**
20:00 – 22:00 hours (*n*= 326)	-0.06 (-0.046 to 0.034)	0.013 (-0.023 to 0.048)	0.017 (-0.025 to 0.060)	**0.100 (0.030 to 0.168)**

Standardized beta's (with 95% confidence intervals in brackets) from linear mixed model analyses with a random intercept and slope over time (one-hour periods), nested within the dates at which measurement commenced. Results were adjusted for age, gender, average temperature, average duration of rainfall, and average duration of sunshine per day. Bold number represents statistical significance at $p<0.05$. Network distance showed comparable results: see supplemental Table 1 in Appendix 4.

Discussion

This study investigated the association between playability of school-environments and ASPA, separately for time-periods within the after-school period and distance-categories from school to children's residence. We demonstrated that the influence of playability is highly dependent on these time-periods and distance from home to their school: greater distance attenuated the influence of playability of the school-environment on ASPA, especially in the first hours after-school. As expected, children that lived outside the study-area for which playability was audited generally showed no relationships between playability of the school-environment and ASPA.

When comparing our findings in the light of other studies that have investigated ASPA objectively, we can confirm that boys were more active after-school compared to girls (17, 20, 25). In contrast to the study of Mota et al., which reported that boys were more active in the later time-periods after school (19), we found that the difference between boys and girls was stable across the first three time-segments, and this difference decreased at later periods in the evenings (data not presented). As this study did not compare PA during school hours with ASPA, we cannot compare our results with studies that indicated that ASPA significantly contributed to total PA (17, 20, 21). Although Timperio et al. found that relationships between ASPA and individual features of public open spaces were different for boys than for girls (22), we found no such moderation mechanisms in our playability index. This may be because in our study, potential gender differences may annul at a higher level of abstraction when utilizing a standardized index-score of playground qualities instead of individual features of public open spaces. Further research is however needed to clarify potential gender-related moderation mechanisms. In addition, Scott et al., argued that perceptions of easy access and the number of PA-facilities, but not objectively determined number and proximity of PA-facilities were related to adolescent girls' non-school PA (24). Although we acknowledge the importance of perceived accessibility and/or presence of environmental attributes in PA-research, we cautiously suggest that this played a relatively minor role in our study because our playability index aggregated qualities of multiple playgrounds, accounting for accessibility and the number of these playgrounds in the school-environment.

When taking into account the relatively small strata-specific sample sizes at greater distance-categories, relationships may seem relatively weak. However, this study demonstrated that relevant relationships between physical environments and ASPA can be revealed and made plausible, with increasing specificity in time and distance. This demonstrates that loss of statistical power due to lower number of observations is compensated by increased discriminative precision thanks to time-place specificity.

Our proposed playability score allowed for aggregation of playground characteristics of the school-environment within multiple geographic settings. The SPACE observation instrument is comparable to the Neighborhood Environment Walkability Index in terms of identified factors/scales (e.g. facilities, aesthetics, proximity, accessibility), aggregation

procedure (computation of means from subscale items), and normalization procedures (37, 38). The concept of playability was introduced in the studies of Frank and Roberts (6, 41). As the study of Roberts solely reported on a protocol of developing a playability-index, to date no direct comparisons can be made with the current study's SPACE observation instrument. The study of Frank et al. (6) derived the quantity and quality of public parks using the Environmental Assessment of Public Recreational Spaces (EAPRS). With the exception of the quality-concept 'shade' and trails, all concepts and methodology of EAPRS (i.e. independent audits of two trained observers) were also represented in the current study.

One may argue that our results are not influenced by differences in playability, but by differences between schools in active transport. However, we found no indication for a ASPA-increase in children who lived more than 800 meters from their school at later time-periods (potentially to compensate for motorized transport). In addition, children reported the number of days per week they walked or cycled to school and the mean duration of those trips, and sensitivity analyses revealed that additional adjusting for active transport did not alter our results (data not shown). As our sample size did not allow further segregation for active transport use, we recommend future research to address the influence of active transport in this relationship.

Our time-specific analyses showed that LPA performed after 20:00 hours was significantly related to playability. This was unexpected because in the Netherlands, during this time of the year it was dark. As we had no diaries, we were unable to confirm to what extent and where children were active at that time. Apart the possibility that relationships in the late evening may be influenced by the relatively small sample sizes because of non-weartime periods, we can only speculate that that this behavior may be merely related to LPA inside their houses, or that potential differences (by chance) between schools in bed-times may have influenced this association, rather than the actual influence of playability of the environment. The same explanation may suffice for unexpected statistically significant relationships between MVPA and playability in children living more than 1600 meters from their school. In addition, we observed that the MVPA percentages increased between 18:00–20:00, but strength of relationships between MVPA and playability did not increase accordingly. This potentially means that the observed increase in mean MVPA percentages was explained by other factors than playability of the environment, such as sports participation (organized forms of after-school activity often occur during evening-hours). Future studies are advised to include some diaries about sleep times and main activities after school (e.g. organized sports participation in the evenings), and are warranted to examine potential if attenuation of playability by organized sports participation would persist in spring, and whether breaks in organized sports (e.g. during summer recess) would relate to a stronger relationship between playability and PA after-school-time.

Strengths and weaknesses

The major strength of this study is that we attempted to improve the understanding of ASPA and a potentially plausible relationship with playability of the physical environment, by measuring time-period specific ASPA and detailed, qualitative characteristics of playgrounds in school-environments.

The present study was confined to an ecological design, assessing characteristics at the school level. Recent methodological innovations such as combined accelerometry and GPS measurements can provide opportunities for even more in-depth analyses of the association between environmental attributes and domain- specific PA. GPS measurements can for example be used to identify time spent outside (26) or even at the schoolyard or at specific playgrounds (42). Moreover, integrating multiple data-sources (e.g. accelerometry, GPS, GIS, audits, school's time tables, participant diaries) into comprehensive databases provide unique opportunities for investigating PA and other health behaviors, while accounting for its spatial and temporal specificity (8, 43).

This study applied a threshold of 50% period-specific registration time to prevent our analyses being influenced by short- spurious spikes of (intense) PA. Although two studies also used this 50% threshold (27, 34) and one study used a 60% threshold (26), reliability and relative influence of exact thresholds for period-specific registration times are debatable. In addition, the definition of non-weartime periods (e.g. 60 minutes of consecutive zero's) highly influences period-specific thresholds, as it determines whether relatively short- or longer bouts of inactivity are classified as non-weartime periods. Future studies are therefore warranted to investigate the influence of period-specific thresholds in depth while also accounting for differences in non-weartime definitions; for example by comparing its influence in relationships with ASPA patterns.

One can speculate on alternative protocols in computing playability (e.g. multiplication of individual items or based on unequal weights). However, as we were unable to find an evidence-base for such alternative protocols, we decided to aggregate based on equal weights. To check for potential errors in the aggregation procedure we fed back the aggregated scores to the auditors of school-environments. Hereafter, no alterations were made to the aggregation protocol.

As our audits were limited to 800 meter buffers from participating schools, it may seem logical that the relationship between playability of the school-environment and ASPA attenuated for children that lived outside this study-area. However, the aim of the present study was to demonstrate the temporal and site-specific mechanisms, and thus underline that in future research investigating relationships between PA and the environment, time- and place specificity is warranted. In addition, as in the Netherlands no public primary schools have organized public transport services from school to children's homes and the majority of 8-11 children rely on active transport to get home after school, all children are likely to have at least the opportunity to be exposed to PA-opportunities in their school-environment.

As data collection was conducted in autumn, our results may not be comparable with other studies that usually perform their PA measurements in spring. Future studies are therefore encouraged to replicate this methodology in spring (or expressly study modification by season). In addition, one-third of the children in our sample experienced one hour earlier sunset due to daylight savings time change in fall. Similarly to the results of Goodman et al (44), we found that children measured in the period with earlier sunsets were less active, both in LPA and MVPA, independent of other meteorological measures (results not shown). In addition, differences in children's PA were especially noticeable in the evenings (data not shown). Because of the relatively unequal distribution of participants measured during daylight saving time versus standard time and our limited sample size, we were unable to check whether the association between playability and ASPA differed between children measured with daylight saving periods versus standard time.

Impact

We found playability to be related with ASPA only in the time-period directly after-school, especially in children who live within 800 meters distance from their school. First, this showed that children who lived further away from school, were relatively confined to their own residential neighborhood after-school, thus making limited use of the school-environment for ASPA. Second, playgrounds in school-environments only had a limited influence on children's ASPA throughout the day, and competing PA-domains (e.g. sports participation) may have explained variability in especially MVPA percentages in later time-periods of the day.

Conclusion

This study demonstrated the importance of playability of school-environments as an environmental determinant of after-school PA in children. With time and space filtering, the conceptual understanding of ASPA and its association with the physical environment can be improved. This may help to develop more tailored interventions to promote specific PA-domains at specific time-periods during the day. All in all, our analytical design with time and space filtering may encourage researchers to look into more domain-specific parts of children's PA behavior within the opportunities and limitations of their own sample, embedded in strong theoretical foundations.

Acknowledgement

We are grateful to the children and schools participating in this study. This study was funded by the Netherlands Organization for Health Research and Development (ZonMW), project number 200130003. All authors declare they have no competing interest.

Author's contributions

TR drafted the manuscript and performed the analyses. DVK, SdV and SK participated in the design of the study. DVK coordinated the study and cooperated with TR in early stages of the rationale. SdV provided expertise on the measurement of environmental attributes. CT helped to draft the manuscript and critically assessed statistical analyses. All authors read and approved the final manuscript.

Competing interest

All authors declare they have no competing interest

Funding

This study was funded by the Netherlands Organization for Health Research and Development (ZonMW), project number 200130003.

References

1. Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth: a review. American Journal of Preventive Medicine. 2011;41(4):442-55.
2. Ding D, Gebel K. Built environment, physical activity, and obesity: What have we learned from reviewing the literature? Health & Place. 2012;18(1):100-5.
3. Sallis JF. Measuring physical activity environments: a brief history. American Journal of Preventive Medicine. 2009;36(S4):86-92.
4. Brownson RC, Hoehner CM, Day K, Forsyth A, Sallis JF. Measuring the built environment for physical activity: state of the science. American Journal of Preventive Medicine. 2009;36(S4):99-123
5. Tucker P, Irwin JD, Gilliland J, He M, Larsen K, Hess P. Environmental influences on physical activity levels in youth. Health & Place. 2009;15(1):357-63.
6. Frank LD, Saelens BE, Chapman J, Sallis JF, Kerr J, Glanz K, et al. Objective assessment of obesogenic environments in youth: geographic information system methods and spatial findings from the neighborhood impact on kids study. American Journal of Preventive Medicine. 2012;42(5):47-55.
7. Saelens BE, Frank LD, Auffrey C, Whitaker RC, Burdette HL, Colabianchi N. Measuring physical environments of parks and playgrounds: EAPRS instrument development and inter-rater reliability. Journal of Physical Activity and Health. 2006;3(S1):190-207.
8. Klinker C, Schipperijn J, Christian H, Kerr J, Ersboll A, Troelsen J. Using accelerometers and global positioning system devices to assess gender and age differences in children's school, transport, leisure and home based physical activity. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1):8.

9. Giles-Corti B, Timperio A, Bull F, Pikora T. Understanding physical activity environmental correlates: increased specificity for ecological models. Exercise and Sport Sciences Reviews. 2005;33(4):175-81.
10. Saelens BE, Handy SL. Built environment correlates of walking: a review. Medicine & Science in Sports & Exercise. 2008;40(S7):550.
11. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJ, Martin BW, et al. Correlates of physical activity: why are some people physically active and others not? The Lancet 2012; 380(9838):258-71.
12. Timperio A, Reid J, Veitch J. Playability: built and social environment features that promote physical activity within children. Current Obesity Reports. 2015;4(4):460-76.
13. Stanley RM, Ridley K, Dollman J. Correlates of children's time-specific physical activity: a review of the literature. International Journal of Behavioral Nutrition and Physical Activity. 2012;9(1):50.
14. Leslie E, Kremer P, Toumbourou JW, Williams JW. Gender differences in personal, social and environmental influences on active travel to and from school for Australian adolescents. Journal of Science and Medicine in Sport. 2010;13(6):597-601.
15. Pate RR, Trost SG, Felton GM, Ward DS, Dowda M, Saunders R. Correlates of physical activity behavior in rural youth. Research Quarterly for Exercise and Sport. 1997;68(3):241-248.
16. Atkin AJ, Gorely T, Biddle S, Marshall SJ, Cameron N. Critical hours: physical activity and sedentary behavior of adolescents after school. Pediatric Exercise Science. 2008;20(4):446-56.
17. Tudor-Locke C, Lee SM, Morgan CF, Beighle A, Pangrazi RP. Children's pedometer-determined physical activity during the segmented school day. Medicine & Science in Sports & Exercise. 2006;38(10):1732-1738.
18. Hager RL. Television viewing and physical activity in children. Journal of Adolescent Health. 2006;39(5):656-61.
19. Mota J, Santos P, Guerra S, Ribeiro JC, Duarte JA. Patterns of daily physical activity during school days in children and adolescents. American Journal of Human Biology. 2003;15(4):547-53.
20. Beighle A, Morgan CF, Le Masurier G, Pangrazi RP. Children’s physical activity during recess and outside of school. Journal of School Health. 2006;76(10):516-20.
21. Fairclough SJ, Beighle A, Erwin H, Ridgers ND. School day segmented physical activity patterns of high and low active children. BMC Public Health. 2012;12(1):406.
22. Timperio A, Giles-Corti B, Crawford D, Andrianopoulos N, Ball K, Salmon J, et al. Features of public open spaces and physical activity among children: Findings from the CLAN study. Preventive Medicine. 2008;47(5):514-8.
23. Dowda M, McKenzie TL, Cohen DA, Scott MM, Evenson KR, Bedimo-Rung AL, et al. Commercial venues as supports for physical activity in adolescent girls. Preventive Medicine. 2007;45(2):163-8.

24. Scott MM, Evenson KR, Cohen DA, Cox CE. Comparing perceived and objectively measured access to recreational facilities as predictors of physical activity in adolescent girls. Journal of Urban Health. 2007;84(3):346-59.
25. Hubbard K, Economos CD, Bakun P, Boulos R, Chui K, Mueller MP, et al. Disparities in moderate-to-vigorous physical activity among girls and overweight and obese schoolchildren during school-and out-of-school time. International Journal of Behavioral Nutrition and Physical Activity. 2016;13(1):39.
26. Cooper AR, Page AS, Wheeler BW, Hillsdon M, Griew P, Jago R. Research Patterns of GPS measured time outdoors after school and objective physical activity in English children: the PEACH project. International Journal of Behavioral Nutrition and Physical Activity. 2010;7(1):31.
27. Arundell L, Ridgers ND, Veitch J, Salmon J, Hinkley T, Timperio A. 5-year changes in afterschool physical activity and sedentary behavior. American Journal of Preventive Medicine. 2013;44(6):605-11.
28. Dale D, Corbin CB, Dale KS. Restricting opportunities to be active during school time: do children compensate by increasing physical activity levels after school? Research Quarterly for Exercise and Sport. 2000;71(3):240-8.
29. Veitch J, Salmon J, Ball K. Children's active free play in local neighborhoods: a behavioral mapping study. Health Education Research. 2008;23(5):870-9.
30. Van Kann DH, Jansen MW, de Vries SI, de Vries NK, Kremers SP. Active Living: development and quasi-experimental evaluation of a school-centered physical activity intervention for primary school children. BMC Public Health. 2015;15(1):1315.
31. Troiano RP. Large-scale applications of accelerometers: new frontiers and new questions. Medicine & Science in Sports & Exercise. 2007;39(9):1501.
32. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. Journal of Sports Sciences 2008;26(14):1557-65.
33. Trost SG, Pate RR, Freedson PS, Sallis JF, Taylor WC. Using objective physical activity measures with youth: how many days of monitoring are needed? Medicine & Science in Sports & Exercise. 2000;32(2):426-31.
34. Ridgers ND, Timperio A, Crawford D, Salmon J: Five-year changes in school recess and lunchtime and the contribution to children's daily physical activity. British Journal of Sports Medicine. 2011.
35. Aarts MJ, de Vries SI, Van Oers HA, Schuit AJ. Outdoor play among children in relation to neighborhood characteristics: a cross-sectional neighborhood observation study. International Journal of Behavioral Nutrition and Physical Activity. 2012, 9(1):98.
36. De Vries SI, Hopman-Rock M, Bakker I, Hirasing RA, Van Mechelen W. Built environmental correlates of walking and cycling in Dutch urban children: results from the SPACE study. International Journal of Environmental Research and Public Health. 2010;7(5):2309-24.

37. Rosenberg D, Ding D, Sallis JF, Kerr J, Norman GJ, Durant N, et al. Neighborhood Environment Walkability Scale for Youth (NEWS-Y): reliability and relationship with physical activity. Preventive Medicine. 2009;49(2):213-8.
38. Saelens B, Sallis J, Black J, Chen D. Neighborhood-based differences in physical activity: an environment scale evaluation. American Journal of Public Health. 2003;93(9):1552-8.
39. Bekkers VJ, de Kool, D, Straten, GF. Educational Governance: Strategy, development, and effects: NWO/Beleidsgericht Onderzoek Primair Onderwijs. Rotterdam; 2012.
40. Herweijer L, Vogels, R. Parent's perceptions about pedagogy and schools. The Hague: Netherlands Institute of Government; 2004.
41. Roberts JD, Ray R, Biles AD, Knight B, Saelens BE. Built environment and active play among Washington DC metropolitan children: A protocol for a cross-sectional study. Archives of Public Health. 2015;73(1):22.
42. Van Kann DH, de Vries SI, Schipperijn J, de Vries NK, Jansen MW, Kremers SP. Schoolyard Characteristics, Physical Activity And Sedentary Behavior: combining GPS and Accelerometry. Journal of School Health. 2016;86(12):913-21.
43. Hurvitz PM, Moudon AV, Kang B, Saelens BE, Duncan GE. Emerging technologies for assessing physical activity behaviors in space and time. Emerging Technologies to Promote and Evaluate Physical Activity 2014:8.
44. Goodman A, Page AS, Cooper AR. Daylight saving time as a potential public health intervention: an observational study of evening daylight and objectively-measured physical activity among 23,000 children from 9 countries. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1):84.

CHAPTER 8

Critical hours and important environments: relationships between afterschool physical activity and the built environment using GPS, GIS and accelerometers in 10-12-year-old children.

This chapter will be published as:

Remmers T, Thijs C, Ettema D, de Vries SI, Slingerland M, Kremers SP. Critical Hours and Important Environments: Relaitonships between after-school physical activity and the built environment using GPS, GIS and accelerometers in 10-12-year-old children.

Abstract

Introduction: The afterschool time segment is considered a promising period for Physical Activity (PA) promotion in children. In this time segment, characteristics of the built environment may play an important role. Therefore, the objective of this study was to assess relationships between features of children's environment and context-specific afterschool leisure time PA and active transport, with the emphasis on relationships with greenspace environment, roads, and publically accessible playgrounds.
Methods: Children participated in a 7-day accelerometer- and Global Positioning Systems (GPS) protocol. GPS data-points were overlaid with GIS data using ArcGIS 10.1 software. Afterschool periods were identified based on school schedules and validated individually based on children's GPS locations at their school parcel. Afterschool leisure time PA was identified by filtering from combined accelerometer-GPS data at participant's residence, school, sports grounds, afterschool childcare centres, shopping centres, and in trips. Trips were identified according to previously validated GPS speed-algorithms in the PALMS database. For each child, a multi-place environment was calculated combining home-, school-, and the daily transport (between home and school) environment. GIS-derived features of the built environment were extracted from these mutli-place environments. Multi-level linear mixed models were fitted, adjusted for meteorological circumstances. Outcome measures were afterschool leisure time PA, cycling and walking.
Results: In total, 253 10-12-year-old children from 20 Dutch primary schools provided valid data. Thirteen percent of the afterschool leisure time was spent in moderate-to-vigorous PA (MVPA), while 37% of the afterschool active transport time was spent in MVPA. Afterschool leisure time MVPA was associated with smaller distances from school to home and a higher density of buildings, lawns, shrubs and pedestrian paths. In the same time, higher density of buildings, lawns, and pedestrian paths were associated with fewer minutes of afterschool cycling, while larger multi-place environments and a higher density of pedestrian area's and sports terrains was associated with more minutes of afterschool cycling. Afterschool walking was associated with smaller distances from school to home and a higher density of agriculture, shrubs, main roads, and pedestrian paths.
Conclusion: We demonstrated that with accelerometer and GPS methodologies combined with extensive analyses of GIS data, studies can investigate associations between the specific features of the multi-place built environment and context-specific afterschool PA. The present study showed that greenspaces (i.e. lawns and shrubs) and smaller distances from children's residence to their school were associated with more afterschool leisure time PA and walking among 10-12-year old children. For afterschool cycling different features of children's environment are relevant.

Introduction

The detrimental impact of prolonged sedentary behaviour bouts and insufficient physical activity (PA) on youth health profiles is well established. As physical inactivity tends to track from youth to adulthood (1), promoting physical activity (PA) of children is a crucial component of primary prevention strategies that combat overweight and obesity-related health consequences.

The development of objective measurements (e.g. accelerometry) allows researchers to continuously monitor children's daily PA behaviour, and to investigate separate time periods that are promising for interventions by filtering data-outputs based on time-segments. Acknowledgement of these specific time-segments is essential, as children's PA patterns fluctuate during the day and can be highly context-specific (2, 3). The afterschool period is such a context-specific time-segment that is often referred to as 'critical hours' for PA promotion, because it contributes up to half of the daily amount of moderate to vigorous PA (MVPA) (4), and afterschool PA declines as children reach adolescence (5). During the afterschool period, children have more discretion over the activities in which they engage, leading to a competition of PA pursuits versus technology- or homework-related sedentary activities (5-7). Because of this, afterschool behaviours may reflect more autonomously regulated behaviour, which may be more likely to persist into habits and routines (8, 9). Hence, afterschool PA has been considered highly predictive of overall sustained PA patterns (10), which makes it a primary time-segment for PA interventions (11).

From 2010 onwards, the number of studies that used objective measurements to investigate afterschool PA rapidly increased (12). However, interpretation of these studies' results is limited by two main methodological challenges. First, there are inconsistent definitions of the afterschool time-segment (5). For example, while some studies used generic start time thresholds such as 3 PM (6, 7, 13, 14) or 3:30 PM (15-17), other studies used reported schools' schedules (4, 5, 18-21) or excluded activity during school hours (22). Second, although separately investigating afterschool PA is an important first step in examining context-specific determinants of PA (23), the afterschool period still consists of multiple distinct contexts of PA behaviour (e.g. active transport, organized sports participation, leisure time PA) (18). The ability to measure PA within these contexts is essential, as the influence of potential determinants may depend on these contexts. To date, these behavioural contexts have been unaccounted for. As a result, it is uncertain whether previous studies using objective measurements to investigate afterschool PA represent the actual self-sustained leisure-time afterschool behaviour.
Besides its discretionary character, the afterschool period has the potential to expose children to diverse features (or outdoor PA opportunities) around the school- as well as in their residential environment. Therefore, the role of the social- and physical environment in children's afterschool PA is of special interest. To date, from the six studies that have investigated relationships between afterschool PA and the built environment (16, 19, 22-

25), four studies solely investigated environmental features around the residential neighbourhood (16, 19, 24, 25). However, during the afterschool period, children may spend significant parts of their time outside their residential neighbourhood (26). Therefore, not only the residential environment, but also other environments such as children's school-environment and the daily transport route between home and their school, are of interest when investigating environmental determinants of afterschool PA. Consequently, features of children's so-called multi-place environments (e.g. including school, residence, and daily transport route as spatial anchor points) may be especially suited for investigating associations with PA during the afterschool time-period (27, 28).

A methodology that can help us to increase our understanding of the relationships between features of children's multi-place environments and afterschool PA is Global Positioning Systems (GPS), especially when integrated with accelerometer data. In this way, PA behaviour and GPS-derived geographical location are collected at the same moment in time, which has the potential to assess the influence of contextual exposure by time and place on PA at an individual level (29, 30). Moreover, when integrated with extensive registries of the built environment such as Geographic Information Systems (GIS), researchers can measure underlying characteristics of the environment for each GPS observation. For example, results from earlier GPS-GIS studies suggest that greenspace environments are an important facilitator for PA (22, 31-35). To date, three studies have used accelerometers and GPS loggers to describe the afterschool period (15, 18, 22). GPS loggers can provide essential descriptive information regarding important additional afterschool contexts. For example, with GPS loggers it is possible to investigate the actual self-sustained afterschool leisure time PA, by excluding organized sports participation (based on GPS-derived presence at sports grounds). Likewise, afterschool time-segments may now be individually validated by the actual presence of a child on its school-parcel, rather than based on generic start time thresholds or reported school schedules.

The present study's aim was to assess the relationship between features of children's multi-place environment and afterschool leisure time PA, cycling and walking, using more precise measurements of 1) context-specific afterschool leisure time PA and afterschool active transport in 10-12-year-old children, and 2) children's exposure assessment to objectively-measured multi-place environments using accelerometers, GPS loggers and GIS data.

Methods

Design and participants

The present study analyzed data from the baseline measurement of the PHysical Activity in public Space Environments (PHASE-kids) study, which examined longitudinal relationships between the built-environment and children's PA patterns in the transitional phase from primary- to secondary schools. The PHASE-kids study was conducted in the municipality of 's-Hertogenbosch, which covers around 110 square kilometres, and has

approximately 150.000 residents (36). Population density varies between municipality neighbourhoods (1.8 - 59.0 residents per hectare). Average population density of included neighbourhoods was 19.4 residents per hectare (37). For the baseline measurement, we invited 30 primary schools to participate (initial sample ≈ 1000 children), of which 20 schools agreed to participate. Children in the final year of primary school were all invited to participate in a 7-day accelerometry and GPS monitoring protocol. We recruited children by informing teachers and staff, distributing pamphlets at schools, conducting two educational presentations by the research staff at schools, and by distributing letters for parents or guardians. One year later, participating children were approached again at their secondary school for a follow-up measurement using the same protocol. For the current analyses, only baseline measurements were considered. Ethical approval for the PHASE-kids study was obtained from the research ethics committee of the Maastricht University Medical Centre (reference number 12-4-077).

Baseline data were collected from April till July 2015, with an average daily temperature of 15.12 degrees Celsius (SD=4.96) and 77% of the days with < 1.0mm of precipitation (based on registries from a local municipality weather station). Sunset times during this time-period in the centre of the Netherlands were between 20:13 and 22:06 hours (data extracted from http://www.timeanddate.com/sun/netherlands).

Accelerometers and GPS loggers were distributed during school hours, where children received verbal and written instruction about how to wear the devices. Both devices were attached to the waist and worn at the right hip with a single elastic belt. We instructed children to wear the belt during waking hours for 7 consecutive days, only to remove the belt during water-related activities (e.g. swimming, showering), and to recharge the GPS logger every day before going to sleep. Children were asked to record the times and reasons why they took off the devices in a diary. After measurement, devices were collected by the research-staff during school hours, while the child and one of their parents received a verbal and written invitation for an electronic questionnaire.

Measurements

Socio-demographic measures

Parents reported children's name, school, date of birth and address, directly after providing informed consent to participate in the study. In addition, we assessed whether children from divorced parents were residing at two locations. Schools provided detailed class timetables for the data-collection period. Directly after measurement, children and parents filled in an electronic questionnaire focusing on aspects such as perceived environment, child's (travel) behaviours and homework.

Accelerometer measures

Accelerometers provide reliable and accurate measures of youth's PA patterns (38, 39). In this study, accelerometers (GT3X, ActiGraph, Pensacola, Florida) were set to record data at 30Hz, and accumulated data into 10 second epochs. The manufacturer's software (ActiLife version 6.11.9) was used for initialization and initial screening of data-output. In order to manage the data-load of subsequent analyses, wear time criteria of => 600 minutes of wear time per day for at least two weekdays were applied (40). Weekend days were excluded.

GPS measures

The GPS logger used in this study (BT-Q1000XT, Qstarz International Co, Taipei, Taiwan) has demonstrated relatively good static spatial accuracy compared to other units (41), and acceptable dynamic accuracy (42). GPS and accelerometer devices were worn on the waist and taken off just before bedtime. We used the manufacturer's software (QTravel version 1.46) for initialization and downloading data-output. In order to optimize sample frequency while considering the limited data-storage capacity of the GPS when using a 7-day protocol, devices were set to record data at 10 second epochs. Furthermore, we configured the device to record date, time, longitude, latitude, elevation, speed, signal-to-noise ratio, number of satellites in reach, and to stop logging when storage capacity was full (18).

Data analysis

Data management in PALMS and data reduction

Accelerometer and GPS data were processed using the Personal Activity and Location Measurement System (PALMS), which allows users control over most parameter settings in a web-based application (43, 44). Intensity of accelerometer activity was categorised into sedentary behaviour, light PA (LPA), moderate PA (MPA), and vigorous PA (VPA) according to Evenson's cut-points (45), which performed best in free-living activities of 5-15 year-old children (46). We defined non-wear time as ≥ 20 consecutive minutes of zero accelerometer counts (47). PALMS processed GPS data by filtering invalid values according to extreme speed (i.e. threshold ≥ 130 kmph) and extreme changes in elevation (i.e. threshold ≥ 1000 meters). We applied the same PALMS algorithms (version 4) as Carlson et al. (2015) for trip and trip mode classification (e.g. pedestrian, bicycle) (48), with the exception of the speed-thresholds for bicycling. Namely, the present study applied the default of 10-25 kmph bicycling speed-thresholds, while Carlson et al. (2015) applied thresholds of 10-35 kmph because their sample consisted of commuting cyclists that were expected to accumulate higher cycling speeds. Invalid GPS points were imputed from the last known valid point, for up to 10 minutes. Finally, as our accelerometers had higher storage-capacities than the GPS loggers, and because in the present study we were only interested in their combined data, we ordered PALMS to match data based on start- and end-times of the GPS logger. The PALMS dataset resulted in 10-seconds GPS epochs (e.g. latitude, longitude, trip mode, speed) with timestamp-merged accelerometer data (e.g. activity counts, activity intensity classification).

We exported PALMS datasets separately for each school, and integrated these separate datasets into a PostgreSQL database (http://www.postgresql.com). We first deleted data from pre-selected participants with insufficient accelerometer wear time. Subsequently, based on reports from the school principal, we performed queries to identify relevant time-segments based on individual school's schedules, and these separate datasets were subsequently merged into one time-segmented dataset (i.e. afterschool and the last 60 minutes in-school datasets).

Time-segmented datasets, containing both accelerometry and GPS data, were integrated into ArcGIS version 10.4.1 (ESRI, Redlands, California). Additionally, we overlaid GIS-data from the municipality of 's-Hertogenbosch, which contained detailed geospatial information regarding for example buildings, roads, land-use, and facilities. These time-segmented datasets consisted of millions of records. We applied basic validation rules by deleting records (i.e. 10-second epoch measurements) with incidental missing accelerometer data, or records that were located outside the municipality study-area. In accordance with previous studies investigating afterschool time-segments (5, 15, 23), we ensured reliability of the time-segment by only selecting records from days with > 4 hours of valid wear time in the afterschool time-segment (see Figure 1).

Spatial analyses to validate afterschool time-segments

Subsequent spatial analyses were conducted in order to 1) filter afterschool leisure time context from other afterschool contexts, and 2) define children's exposure to features of their multi-place environment (i.e. school, residence, and daily transport environment). We geo-located the residential and school buildings and accompanied geo-referenced parcels for each participant's residence and school, using ArcGIS geocode-functionality and the municipality's address-database. Subsequently, we validated children's precise afterschool time-segments by calculating the daily percentage of GPS points that were within a distance of 10 meters to their school's geographic parcel during the last hour of school time. A buffer of 10 meters was chosen to account for potential imprecision of the GPS logger (18, 49, 50). Time-segments from children with < 80% of their GPS points within the school-parcel during this last hour of school time, were carefully inspected in individual ArcGIS maps, and the majority of the accompanied days were deleted from the afterschool dataset (see Figure 1). Nevertheless we retained such data in some instances because they represented short walking trips outside the school-parcel in order to participate in physical education classes at neighbouring sports halls or fields, or slight erroneous deviations of the GPS-signal due to urban canyoning (50).

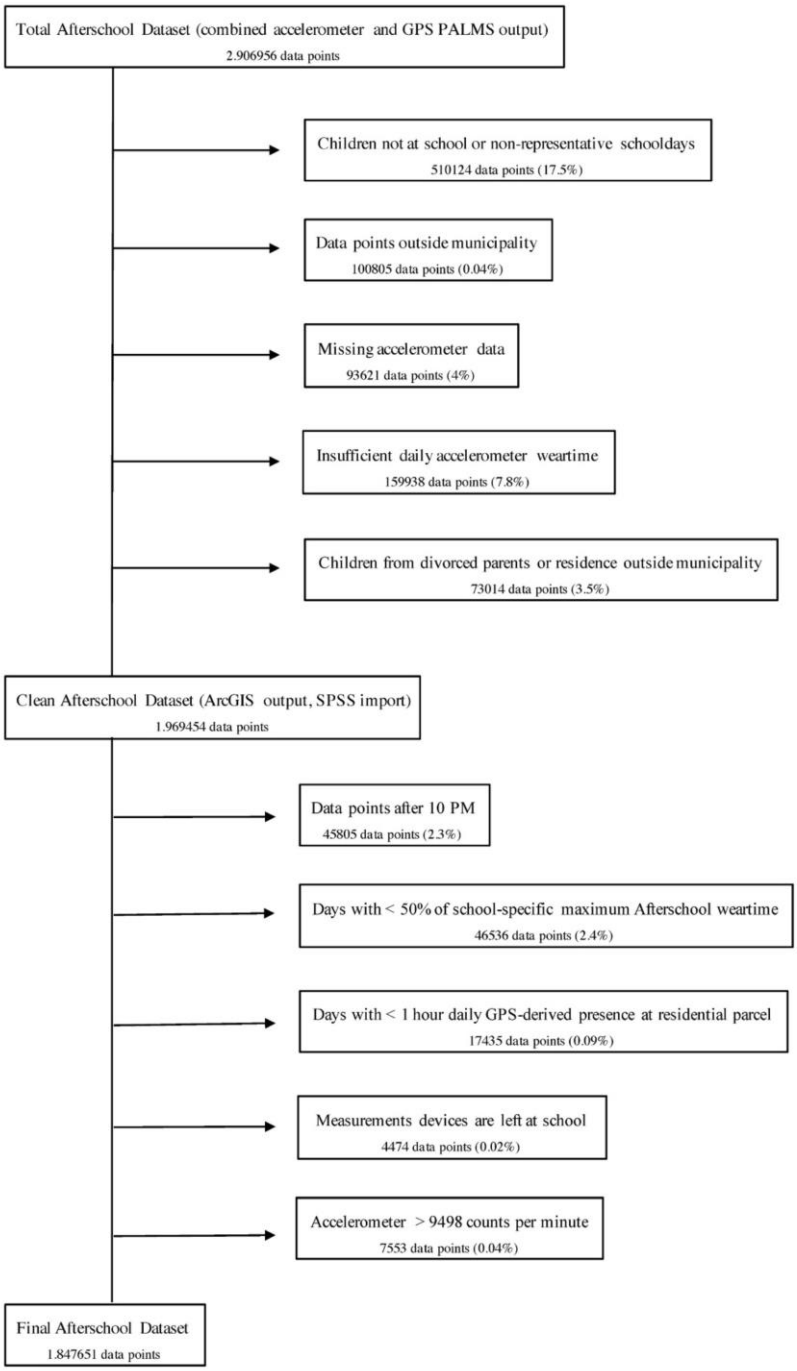


Figure 1: Data Flowchart

Spatial analyses of multi-place environments

We computed a 400-meter buffer surrounding a participant's school and residence. We also computed a 200-meter buffer surrounding the shortest path between participant's school and residence along the street network. Subsequently these three buffers were combined into an individualized multi-place environment using the dissolve function in ArcGIS. Relevant GIS-data from the municipality of 's-Hertogenbosch was extracted from these multi-place environments, using the spatial join and summarize functions in ArcGIS (see Figure 2). This GIS-data consisted of two levels of detail. In first detail-level, we identified the categories: vegetated terrain, water, buildings, and roads. Second level of detail consisted of road-categories (e.g. cycling path, rural road, highway, parking spots), and vegetated terrain appearances (e.g. woods, lawn, shrubs, agriculture, etc.). For each respondent, we first computed the total area (in square meters) of their multi-place environment, and the specific area (in square meters) that was assigned to each of the built-environment features (e.g. woods, roads). For each of the built-environment features, we computed the proportion of area assigned to that specific feature, relative to the total area. For example, a participant's exposure to bicycling paths was quantified as the area (in square meters) of bicycling paths within its individual buffer, relative to the total buffer-size of the participant's multi-place environment.

Operationalization of the leisure time and active transport contexts

Based on the GPS-derived context information and hierarchical decisions of Klinker et al. (2014), we first identified the domain ‘home’ by selecting records that were within 10 meters of each respondent's self-reported residential-parcel from all GPS points in the afterschool time-segment (Table 2). Second, we identified four other subdomains by identifying records within 10 meters from the school parcel, sports facilities, shopping centres or malls, or afterschool childcare. Third, for transport, we applied the above-described PALMS speed-thresholds. As bicycling and walking may be influenced by distinct environmental features, we investigated bicycling and walking separately. Fourth, all other non-defined records were identified as afterschool leisure time performed at other locations (e.g. at friend's homes, in parks, etc).

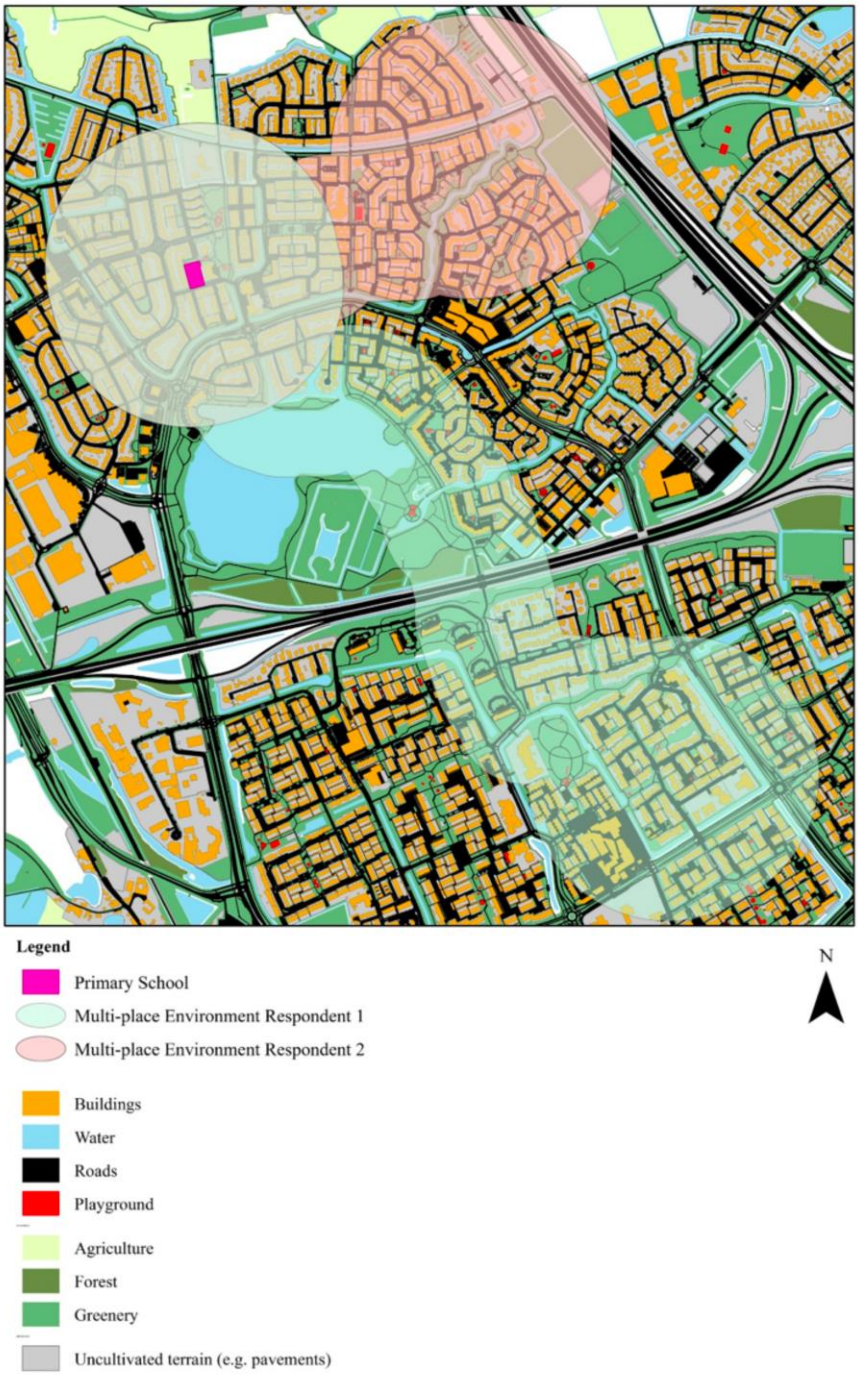


Figure 2: Example of multi-place environment and accompanied GIS data

Statistical analyses

Days were used as the unit of analysis because this allows examining day-to-day variation within children. After presenting participant characteristics (Table 1), we present the median and interquartile ranges (IQR) for children's daily contribution to several domains and subdomains (Table 2) (51).

In our multivariate explanatory analyses, we focused on the leisure time and the active transport domain. In the leisure time domain, we associations were separately analyses by LPA and MVPA. In contrast, in the active transport domain (i.e. cycling and walking), we combined LPA and MVPA intensity-categories. The first set of independent variables were meteorological variables, accessed from a local municipality weather station's hourly registry. The second set of independent variables were variables from the multi-place environments, in which we focused on publically accessible environmental features accessed from the municipality's GIS registry. All multivariate analyses were performed using multilevel linear mixed models with a repeated term for days within children and a random term for school, accounting for the nested structure of measurement days within children and children within schools. Normality of residuals was inspected using normal probability plots. As all of our model-residuals showed significant deviation from normality, we transformed our dependent variables using log-transformations, while replacing all zero values with a minimal value of 0.01 square meters. Subsequently, model fit of these models were inspected and tested against the non-transformed variant to verify its fitting capabilities. To facilitate comparisons between independent variables, we calculated standardized log-transformed coefficients by dividing each log-transformed model-coefficient by its standard error.

In analyses containing second level GIS-features of the built-environment, a manually executed stepwise procedure was followed to control and investigate the impact of potential multicollinearity issues. Namely, first we investigated associations between our dependent variables and all first-level GIS variables, adjusting for baseline variables (i.e. wear time, age, gender, and meteorology; see Table 3). Second, we replaced the first-level GIS variables with the accompanied second-level GIS variables, and tested these associations apart from each other. Third, we simultaneously entered second-level variables with strong associations ($p < 0.10$), and deleted variables with the largest p-value; only retaining variables that were statistically significant ($p < 0.05$). Baseline variables were not deleted from these models. An exception was made for the playground-variable (as this may be especially relevant for urban planning), from which we presented its association with leisure time PA regardless of its P-value.

Moderation analyses were performed for gender by interaction terms and inspecting stratum-specific results, but significant interactions were not found. Likewise, we also investigated moderation for the daily minutes that respondents spent in their multi-place environment (based on their GPS location), but no such moderation was found. Statistical analyses were performed using SPSS 21.0 for Windows (IBM SPSS Inc., Armonk, NY), and $p < 0.05$ indicated statistical significance.

Results

Participant characteristics

In total, 117 boys and 138 girls from 20 primary schools provided valid data. Children were approximately 12 years old. After data-cleaning and applying exclusion criteria, 808 valid days of measurement were retained and 74% of the children provided valid data for at least three days. This resulted in a dataset of around 1.8 million records (i.e. 10-second epochs), which held around 5000 hours of afterschool data collection. Results from an electronic questionnaire that was administered after the measurements (response rate 77% and 75% for the children and parents, respectively), shows that this sample consisted of children from parents with relatively high socio-economic status; 44% of responding parents had at least a higher vocational diploma, and 67.9% of the responding parents had a paid job for at least three days per week. On average, children lived 696.1 meters (SD=735.3) from their school. In total, 92% of the parents reported that their child used active transport to travel to and from school. In addition, 77% reported that their child spent equal or less than 10 minutes per day on afterschool homework (Table 1).

Table 1: Characteristics of the study population (*N* = 255)

	n (%)
Gender; *n* boys (missing *n* = 0)	117 (45.9%)
Age; mean years (SD) (missing *n* = 0)	12.1 (0.5)
Valid measurement-days; *n* ≥ 3 days (missing *n* = 0)	189 (74.1%)
Respondent questionnaire; *n* mothers (missing *n* = 54 (21.2%))	146 (57.3%)
Most frequently used transport-mode to school; *n* bicycling (missing *n* = 59 (23.1%))	128 (50.2%)
Most frequently used transport-mode to school; *n* walking (missing *n* = 59 (23.1%))	52 (20.4%)
Average daily time spent on homework during measurement; *n* ≤ 10 minutes (missing *n* = 59 (23.1%))	150 (58.8%)
Educational level of respondent; *n* secondary vocational or higher education (missing *n* = 59 (23.1%))	142 (55.7%)
Educational level of respondent's partner; *n* secondary vocational or higher education (missing *n* = 59 (23.1%))	127 (49.8%)
Employment of respondent; *n* ≥ 3 days of paid employment (missing *n* = 59 (23.1%))	133 (54.0%)
Employment of respondent's partner; *n* ≥ 3 days of paid employment (missing *n* = 92 (36.1%))	151 (59.2%)

Participant's afterschool behaviour in various contexts

On average, children spent the highest percentage of afterschool active minutes (i.e. combined LPA and MVPA) on sports grounds (41% in MVPA) and active transport (37% in MVPA). Most of the children participated in these activities at least once in the measurement period. Children spent the lowest average percentage of active minutes afterschool on their residential parcel (4% in MVPA). During afterschool leisure time, 13% of the minutes were moderate-to-vigorously active (Table 2). We investigated the amount of time that children spent in their multi-place environment (i.e. within school, residence and daily transport buffer; Figure 2). We found that in approximately 65% of the days, children spent at least 80% of their afterschool time within their multi-place environment. This was similar for leisure time and active transport (i.e. 68% and 63%, respectively). This means that the vast majority of children's afterschool leisure time and active transport behaviour occurred within their multi-place environment.

Meteorological circumstances

Meteorological circumstances significantly affected children's leisure time PA and transport PA. Days with at least 0.2 mm of total rain (versus no rain) were associated with less MVPA leisure time and fewer active minutes in cycling and walking. In addition, higher temperatures were related with more active minutes while cycling and less activity in MVPA leisure time (Table 3). In subsequent models, meteorological circumstances were controlled for.

Association between PA and first-level environmental features

Larger multi-place environments, typically the case for children that lived further from their school (Figure 2), were associated with less active minutes of walking after school, and more active minutes of cycling. First-level environmental features were not associated with afterschool leisure time PA. In afterschool active transport, however, higher spatial density of roads and buildings were related with less active minutes of cycling, while a higher density of roads on the other hand, was related to more minutes of walking (Table 3).

Association between afterschool leisure time PA and second-level built environment features

Relationships between second-level features of the built-environment and leisure time PA are shown in Table 4. Multi-variate results showed that smaller multi-place environments and higher spatial densities of agriculture, lawns, shrubs, and local roads were associated with more minutes of leisure time PA of light intensity. Higher density of highways was associated with less minutes of light intensity leisure time PA. In addition, more active minutes of leisure time of MVPA intensity were associated with smaller multi-place environments and a higher density of buildings, lawns, shrubs and pedestrian paths. A higher density of playgrounds was not associated with more minutes of leisure time PA.

Table 2: Afterschool Physical Activity in Contextual Domains

	N of participants	Unadjusted median (IQR)			*n* of days
		Total minutes	Minutes in Light PA	Minutes in MVPA	≥ 80% of time within multi-place buffer
Residential parcel	253	239.3 (138.7)	89.8 (57.4)	8.3 (14.2) [1]	790 (100%)
School grounds	233	33.5 (73.3)	15.5 (33.0)	13.5 (35.0) [2]	640 (100%)
Sports grounds	214	100.2 (55.2)	54.8 (34.7)	41.0 (29.3) [2]	202 (42.3%)
Afterschool childcare	144	19.8 (39.7)	10.0 (21.7)	2.2 (13.2) [2]	181 (67.0%)
Shopping centres	220	79.5 (105.1)	44.5 (58.5)	8.0 (11.0)	216 (45.6%)
Active transport	253	40.3 (32.7)	23.3 (22.3)	15.0 (17.5)	480 (63.3%)
Passive transport	186	19.5 (14.7)	10.3 (8.2)	1.8 (2.3)	45 (13.8%)
Other: Leisure time	255	171.2 (136.2)	81.5 (71.5) [1]	22.3 (24.8)	544 (68.0%)

Gender differences were investigated using log-transformed multilevel linear mixed models, adjusting for context-specific wear time, age, and nested structure of days within children and children within schools. Children that did not participate in a specific context did not contribute to the calculation of the median minutes [1]: significantly lower for boys vs. girls, [2]: significantly higher for boys vs. girls.

Table 3: Multivariate associations between minutes spent in Afterschool Leisure Time Physical Activity and First Level Geographic Information within the multi-place environment

	Leisure time LPA [1]		Leisure time MVPA [2]		Bicycling [3]		Walking [4]	
	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*p*-value
Wear time (total minutes in leisure time)	31.38	< 0.001	12.56	< 0.001	-1.09	0.28	0.15	0.88
Gender (boys vs. girls)	-1.53	0.13	2.38	0.02	-0.95	0.34	0.26	0.79
Age (years)	-2.35	0.02	-1.68	0.09	0.44	0.66	-0.76	0.45
Temperature (mean degrees Celsius)	-0.33	0.74	-1.80	0.07	2.83	0.01	1.49	0.14
Atmospheric pressure (mean hPa)	0.94	0.35	0.04	0.97	2.94	< 0.001	1.85	0.07
Rain (0.2 - 10.0 mm vs. no rain)	-0.14	0.89	-2.63	0.01	-3.14	< 0.001	-1.84	0.07
Wind (mean kmph)	-0.60	0.55	-0.54	0.59	1.32	0.19	-1.10	0.27
Solar exposure (UV index)	2.45	0.01	1.28	0.20	0.71	0.48	-1.90	0.06
Total area school-home buffer (per 10 square km)	-1.51	0.13	-1.54	0.12	2.40	0.02	-4.05	< 0.001
Roads (per square meters)	0.52	0.60	1.23	0.22	-1.87	0.06	2.06	0.04
Water (per square meters)	-1.06	0.29	0.18	0.86	-0.38	0.71	1.14	0.26
Vegetated terrain (per square meters)	0.06	0.95	-0.84	0.40	-1.35	0.18	1.50	0.13
Buildings (per square meters)	0.32	0.75	0.66	0.51	-4.70	< 0.001	1.37	0.17

Note: Multivariate linear mixed models. Dependent variables are log-transformed and independent variables are standardized. [1] -2 log likelihood= 1383.8, [2] -2 log likelihood= 3085.1, [3] -2 log likelihood= 1377.5, [4] -2 log likelihood= 1711.7.

Table 4: Multivariate associations between minutes spent in Afterschool Leisure Time Physical Activity and Second Level Geographic Information within the multi-place environment

	Leisure time LPA [1]		Leisure time MVPA [2]	
	Coefficient	*p*-value	Coefficient	*p*-value
Total area school-home buffer (per 10 square km.)	-1.85	0.06	-2.12	0.03
Water	-1.44	0.15	0.13	0.89
Buildings	0.87	0.39	1.94	0.05
Vegetated terrain: agriculture	2.28	0.02	-	-
Vegetated terrain: lawns	2.69	0.01	2.50	0.01
Vegetated terrain: shrubs	2.50	0.01	3.38	< 0.001
Roads: highway (120 kmph)	-2.99	< 0.001	-	-
Roads: local road (50 kmph)	3.79	< 0.001	-	-
Roads: pedestrian path	-	-	2.50	0.01
Playgrounds	1.92	0.06	0.05	0.96

Note: Multivariate linear mixed models. adjusted for baseline variables presented in Table 3. Dependent variables are log-transformed and independent variables are standardized. -: variable not statistically significant and therefore not part of final multivariate model. [1] -2 log likelihood= 1355.9, [2] -2 log likelihood= 3069.5.

Table 5: Multivariate associations between minutes spent in Afterschool Bicycling and Walking and Second Level Geographic Information within the multi-place environment

	Bicycling [3]		Walking [4]	
	Coefficient	*p*-value	Coefficient	*p*-value
Total area school-home buffer (per 10 square km.)	2.11	0.04	-4.90	< 0.001
Water	0.35	0.73	0.50	0.62
Buildings	-4.81	< 0.001	1.12	0.26
Vegetated terrain: agriculture	-	-	1.97	0.05
Vegetated terrain: lawns	-2.39	0.02	-	-
Vegetated terrain: shrubs	-	-	2.34	0.02
Roads: main road (100 kmph)	2.29	0.02	2.61	0.01
Roads: pedestrian path	-5.19	< 0.001	3.00	< 0.001
Roads: pedestrian area	4.93	< 0.001	-	-
Sports terrain	2.48	0.01	-	-

Note: Multivariate linear mixed models, adjusted for baseline variables presented in Table 3. Dependent variables are log-transformed and independent variables are standardized. -: variable not statistically significant and therefore not part of final multivariate model. [3] -2 log likelihood= 1338.9, [4] -2 log likelihood= 1698.9.

Association between afterschool active transport and second-level built environment features

Higher densities of buildings, lawns, and pedestrian paths were associated with fewer active minutes of cycling. More minutes of cycling were associated with a higher density of pedestrian area's and sports terrains. Finally, more minutes of walking were related with smaller multi-place environments and a higher density of agriculture, shrubs, main roads, and pedestrian paths.

Discussion

This study examined relationships between features of the built environment, children's afterschool leisure time PA behaviour and afterschool active transport. Our first, more methodological aim, was to investigate context-specific afterschool leisure time and active transport by filtering these contexts from other afterschool contexts, such as organized sports participation. This may be important since previous studies suggested that this may be a confounding factor in the relationship between PA and the built environment (29, 52). We showed that GPS devices provide additional descriptive information about the context of daily PA and mobility patterns, which enables more context-specific analyses of the relations between leisure PA and its environmental determinants (3).
This study showed that greenery density (i.e. lawns and shrubs) was associated with more afterschool leisure time PA and walking, but we found no association with the density of general vegetation. Systematic reviews including studies until 2010, reported a mixed association between environmental greenspaces and PA (53, 54). However, studies from 2010 onwards using objective PA and GPS-determined environmental exposure consistently suggest that children are more active in greenspace environments such as parks (22, 32, 55, 56). Findings from the present study not only support the suggestion that shrubs and lawns (often found in parks) may be important facilitators for children’s PA, but also show that children with a higher density of shrubs and lawns in their multi-place environment, generally perform more afterschool leisure time PA than children with a lower density of these environments (irrespective of whether PA is actually performed around shrubs or lawns). In our view, this may be an important step forward in understanding relationships between greenspace environments and context-specific PA.

From the six studies that investigated relationships between objective afterschool PA and the built environment (16, 19, 22-25), two studies focused on publically accessible features of the environment (19, 23). These studies suggest that not the public open space closest to children's residence is associated with afterschool PA, but also the larger home-school environment or parts thereof. In contrast to the study of Remmers et al. (2016), we found no evidence that higher density of publically accessible playgrounds was associated with more leisure time PA or active transport (23). This may be explained by the fact that GIS data did not enable us to look at quality, maintenance status, or age-appropriateness of these playgrounds. Although this study demonstrated that GIS-data can be used to assess relationships with domain-specific afterschool PA, the quality of GIS

data may depend from one municipality to another. As variability in the quality and data-structure of GIS data hampers between-study comparisons, researchers are encouraged to provide insight in the various levels of detail underlying their spatial analyses.

The present study also aimed to investigate the influence of children's exposure to objectively-measured multi-place environments on physical activity. Systematic reviews investigating relationships between the environment and PA urged for objective measurements of both PA and the built environment (53, 54). Consequently, there has been an increase in studies combining accelerometer and GPS measurements, to investigate relationships between environment and behaviour using contemporaneous momentary designs. In this design, objective data on characteristics of the environment (based on the GPS location) and PA intensity is analysed contemporaneously (22, 32, 35, 55-61). In other epidemiological studies investigating for example air pollution, exposure can be defined as the cumulative time within 50 meters from a certain pollutant regardless of the type of behaviour performed (62). In contrast, PA is a complex interplay between spontaneous and planned behaviour; involving memory of PA facilities, time- and capacity constraints, social interactions, and compensation mechanisms. Therefore, children's actual exposure to PA facilities may not be as time and location dependent as these momentary analyses attempt to capture. Hence, studies using contemporaneous momentary designs should be aware of their limitations. For example, these designs may be especially vulnerable to selective daily mobility bias, which may occur when environments are deliberately visited for PA participation (e.g. sports grounds). In this way, it is not the environment that influences PA, but a participant's pre-conceived choice that biases the PA-environment relationship (27, 29). In contrast to the contemporaneous momentary design, the present study identified accessibility-measures from theory-based spatial anchor points (i.e. participant's residence, primary school and daily transport route). However, as illustrated in Figure 2, our multi-place environments (i.e. school, home and daily transport environment) aggregate to the same neighbourhood environment if children live closer to school. The percentage of 'shared' neighbourhood environment (and thus the added value of using this multi-place environment instead of regular residential or school environments) depends on the distance children reside from their school and the choice of the buffer size. This means that future studies are encouraged to make informed decisions about children's daily exposure environments, based on distances between school and homes, and knowledge of potential other frequently visited anchor points. For example, some studies incorporated participant's own perceptions of their daily mobility environments (63). Moreover, multi-place environments can also be merely considered as children's cognitive activity space in the sense that they have knowledge about relative location of potential PA opportunities from both the school and residential anchor points (22, 27, 29). Consequently, although our exact specification of the buffer areas may thus be under debate, we believe we have used an optimized methodology of assessing objectively measured environmental exposure assessment.

We found that the distance between children's school and their residence was an important determinant of leisure time PA, bicycling and walking. More specifically, greater home-school distances were related to more bicycling, but less leisure time MVPA and walking. As results from the electronic questionnaire showed that the vast majority of our participants used active transport to get to and from school, greater distances may be related to more bicycling as a replacement of walking during the home-school commute (and vice versa). In addition, greater distances may also reflect the subgroup of participants living in neighbourhoods that may be somewhat further away from facilities (e.g. supermarkets or afterschool activities) (64, 65). This was supported by our finding that lower density of buildings and pedestrian paths was also associated with more cycling. In contrast, we found that higher density of buildings was associated with more minutes of leisure time MVPA. Results may be comparable with results from Rodriguez et al., who found increased MVPA in environments with higher population density (65). In addition, we also found some unexpected associations. For example, the negative association between pedestrian areas and cycling. This may be because these pedestrian areas (in contrast to pedestrian paths) were predominantly present in the central business district, where cycling is usually prohibited. These children also lived somewhat further to their primary school, which in turn may explain increased walking and decreased cycling.

Strengths and weaknesses

Study strengths are the utilization of GPS devices in order to investigate associations between the objectively assessed built-environment features (using GIS) and domain-specific PA, adjusting for meteorological differences and the nested structure of measurement-days within children, and children within schools.
This study also had some weaknesses. Although children were instructed to wear the devices during organized sports programs, children sometimes indicated that they removed the devices because they perceived them as uncomfortable. Although fast developing innovations facilitate application of smaller and thus more comfortable devices combining accelerometry and GPS loggers (e.g. smartphone applications), extensive studies are warranted to validate their performance both in PA- and location assessment.

External validity

Although we only investigated data within the municipality border from which GIS data was available, findings of this study may be generalizable to other environments with comparable meteorological circumstances, afterschool time segments, population density and residential density. Also as the Netherlands generally have facilities that support cycling (i.e. separate cycling paths), our results may have limited generalizability to environments with less favourable infrastructure for active transport. In addition, findings of this study may be generalizable to samples with comparable distances from children's residences to their primary schools, and similar motives for active transport. As our sample was considered relatively highly educated, this could imply that child- or parental motives regarding leisure time PA may be different from other samples. In addition, time-

constrains due to competing activities such as organized sports participation or homework may also be considered in comparing results with other studies. However, as we separately investigated bicycling, walking and leisure time, results of leisure time PA may be generalizable to less cycle-friendly environments.

Conclusion

We demonstrated that with combined accelerometer and GPS methodologies, it is possible to investigate associations between the built environment and context-specific afterschool PA behaviour. In addition, detailed GIS data and theory-based spatial analyses enable researchers to further optimize objectively measured environmental exposure assessment. We found that greenspaces (i.e. lawns and shrubs) and smaller distances from children's residence to their school were associated with more afterschool leisure time PA and walking.

References

1. Telama R. Tracking of Physical Activity from Childhood to Adulthood: A Review. Obesity Facts. 2009;2(3):187-95.
2. Fairclough SJ, Butcher ZH, Stratton G. Whole-day and segmented-day physical activity variability of northwest England school children. Preventive Medicine. 2007;44(5):421-5.
3. Giles-Corti B, Timperio A, Bull F, Pikora T. Understanding physical activity environmental correlates: increased specificity for ecological models. Exercise and Sport Sciences Reviews. 2005;33(4):175-81.
4. Hubbard K, Economos CD, Bakun P, Boulos R, Chui K, Mueller MP, et al. Disparities in moderate-to-vigorous physical activity among girls and overweight and obese schoolchildren during school-and out-of-school time. International Journal of Behavioral Nutrition and Physical Activity. 2016;13(1):1.
5. Arundell L, Ridgers ND, Veitch J, Salmon J, Hinkley T, Timperio A. 5-year changes in afterschool physical activity and sedentary behavior. American Journal of Preventive Medicine. 2013;44(6):605-11.
6. De Baere S, Lefevre J, De Martelaer K, Philippaerts R, Seghers J. Temporal patterns of physical activity and sedentary behavior in 10–14 year-old children on weekdays. BMC Public Health. 2015;15(1):791.
7. Hager RL. Television viewing and physical activity in children. Journal of Adolescent Health. 2006;39(5):656-61.
8. Gardner B, Lally P. Does intrinsic motivation strengthen physical activity habit? Modeling relationships between self-determination, past behaviour, and habit strength. Journal of Behavioral Medicine. 2013;36(5):488-97.
9. Hagger MS, Chatzisarantis NL. Intrinsic motivation and self-determination in exercise and sport. Champaigne, IL: Human Kinetics; 2007.

10. O'Connor J, Ball EJ, Steinbeck KS, Davies PS, Wishart C, Gaskin KJ. Measuring physical activity in children: a comparison of four different methods. Pediatric Exercise Sciences. 2003;15(2):202-15.
11. Battista J, Nigg CR, Chang JA, Yamashita M, Chung R. Elementary after school programs: an opportunity to promote physical activity for children. Californian Journal of Health Promotion. 2005;3(4):108-18.
12. Stanley RM, Ridley K, Dollman J. Correlates of children's time-specific physical activity: a review of the literature. International Journal of Behavioral Nutrition and Physical Activity. 2012;9(1):50.
13. Jago R, Fox KR, Page AS, Brockman R, Thompson JL. Physical activity and sedentary behaviour typologies of 10-11 year olds. International Journal of Behavioral Nutrition and Physical Activity. 2010;7(1):59.
14. Nilsson A, Anderssen SA, Andersen LB, Froberg K, Riddoch C, Sardinha LB, et al. Between-and within-day variability in physical activity and inactivity in 9- and 15-year-old European children. Scandinavian Journal of Medicine & Science in Sports. 2009;19(1):10-8.
15. Cooper AR, Page AS, Wheeler BW, Hillsdon M, Griew P, Jago R. Patterns of GPS measured time outdoors after school and objective physical activity in English children: the PEACH project. International Journal of Behavioral Nutrition and Physical Activity. 2010;7(1):31.
16. Lau EY, Barr-Anderson DJ, Dowda M, Forthofer M, Saunders RP, Pate RR. Associations Between Home Environment and After-School Physical Activity and Sedentary Time Among 6th Grade Children. Pediatric Exercise Sciences. 2015;27(2):226-33.
17. Fairclough SJ, Beighle A, Erwin H, Ridgers ND. School day segmented physical activity patterns of high and low active children. BMC Public Health. 2012;12(1):406.
18. Klinker C, Schipperijn J, Kerr J, Ersbøll A, Troelsen J. Context-Specific Outdoor Time and Physical Activity among School-Children Across Gender and Age: Using Accelerometers and GPS to Advance Methods. Frontiers in Public Health. 2014;2(20).
19. Timperio A, Giles-Corti B, Crawford D, Andrianopoulos N, Ball K, Salmon J, et al. Features of public open spaces and physical activity among children: Findings from the CLAN study. Preventive Medicine. 2008;47(5):514-8.
20. Taverno Ross SE, Dowda M, Colabianchi N, Saunders R, Pate RR. After-school setting, physical activity, and sedentary behavior in 5th grade boys and girls. Health & Place. 2012;18(5):951-5.
21. Rushovich BR, Voorhees CC, Davis C, Neumark-Sztainer D, Pfeiffer KA, Elder JP, et al. The relationship between unsupervised time after school and physical activity in adolescent girls. International Journal of Behavioral Nutrition and Physical Activity. 2006;3(1):20.
22. Almanza E, Jerrett M, Dunton G, Seto E, Pentz MA. A study of community design, greenness, and physical activity in children using satellite, GPS and accelerometer data. Health & Place. 2012;18(1):46-54.

23. Remmers T, Van Kann D, Thijs C, de Vries S, Kremers S. Playability of school-environments and after-school physical activity among 8–11 year-old children: specificity of time and place. International Journal of Behavioral Nutrition and Physical Activity. 2016;13(1):82.
24. Scott MM, Evenson KR, Cohen DA, Cox CE. Comparing perceived and objectively measured access to recreational facilities as predictors of physical activity in adolescent girls. Journal of Urban Health. 2007;84(3):346.
25. Dowda M, McKenzie TL, Cohen DA, Scott MM, Evenson KR, Bedimo-Rung AL, et al. Commercial venues as supports for physical activity in adolescent girls. Preventive Medicine. 2007;45(2–3):163-8.
26. Jankowska MM, Schipperijn J, Kerr J. A framework for using GPS data in physical activity and sedentary behavior studies. Exercise and Sport Sciences Reviews. 2015;43(1):48.
27. Perchoux C, Chaix B, Cummins S, Kestens Y. Conceptualization and measurement of environmental exposure in epidemiology: Accounting for activity space related to daily mobility. Health & Place. 2013;21:86-93.
28. Matthews SA, Yang T-C. Spatial Polygamy and Contextual Exposures (SPACEs) Promoting Activity Space Approaches in Research on Place And Health. American Behavioral Scientist. 2013;57(8):1057-81.
29. Chaix B, Meline J, Duncan S, Merrien C, Karusisi N, Perchoux C, et al. GPS tracking in neighborhood and health studies: a step forward for environmental exposure assessment, a step backward for causal inference? Health & Place. 2013;21:46-51.
30. McGrath LJ, Hopkins WG, Hinckson EA. Associations of objectively measured built-environment attributes with youth moderate–vigorous physical activity: a systematic review and meta-analysis. Sports Medicine. 2015;45(6):841-65.
31. Lachowycz K, Jones AP, Page AS, Wheeler BW, Cooper AR. What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity? Health & Place. 2012;18(3):586-94.
32. Wheeler BW, Cooper AR, Page AS, Jago R. Greenspace and children's physical activity: a GPS/GIS analysis of the PEACH project. Preventive Medicine. 2010;51(2):148-52.
33. Southward EF, Page AS, Wheeler BW, Cooper AR. Contribution of the school journey to daily physical activity in children aged 11–12 years. American Journal of Preventive Medicine. 2012;43(2):201-4.
34. Mackett R, Brown B, Gong Y, Kitazawa K, Paskins J. Children's independent movement in the local environment. Built Environment. 2007;33(4):454-68.
35. Quigg R, Gray A, Reeder AI, Holt A, Waters DL. Using accelerometers and GPS units to identify the proportion of daily physical activity located in parks with playgrounds in New Zealand children. Preventive Medicine. 2010;50(5):235-40.

36. CBS Statline: Statistics Netherlands. Population development in municipalities. the Hague 2017. Available from: http://statline.cbs.nl/StatWeb/publications
37. Department of Research and Statistics. Population and area. Statistical yearbook 2015-2016: Municipality of 's-Hertogenbosch; 2016.
38. Corder K, Ekelund U, Steele RM, Wareham NJ, Brage S. Assessment of physical activity in youth. Journal of Applied Physiology. 2008;105(3):977.
39. De Vries SI, Van Hirtum HW, Bakker I, Hopman-Rock M, Hirasing RA, Van Mechelen W. Validity and reproducibility of motion sensors in youth: a systematic update. Medicine & Science in Sports & Exercise. 2009;41(4):818-27.
40. Choi L, Liu Z, Matthews CE, Buchowski MS. Validation of accelerometer wear and nonwear time classification algorithm. Medicine & Science in Sports & Exercise. 2011;43(2):357.
41. Duncan S, Stewart TI, Oliver M, Mavoa S, MacRae D, Badland HM, et al. Portable Global Positioning System Receivers: Static Validity and Environmental Conditions. American Journal of Preventive Medicine. 2013;44(2):19-29.
42. Schipperijn J, Kerr J, Duncan S, Madsen T, Klinker CD, Troelsen J. Dynamic Accuracy of GPS Receivers for Use in Health Research: A Novel Method to Assess GPS Accuracy in Real-World Settings. Frontiers in Public Health. 2014;2:21.
43. The Physical Acitivty and Location Management (PALMS). 2017 [cited 2017 1st of March]. Available from: https://palms.ucsd.edu:8443/PALMS/.
44. Kerr J, Norman G, Godbole S, Raab F, Demchak B, Patrick K. Validating GPS data with the PALMS system to detect different active transportation modes. Medicine & Science in Sports & Exercise. 2012;44:647.
45. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. Journal of Sports Sciences. 2008;26(14):1557-65.
46. Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. Medicine & Science in Sports & Exercise. 2011;43(7):1360-8.
47. Cain KL, Sallis JF, Conway TL, Van Dyck D, Calhoon L. Using accelerometers in youth physical activity studies: a review of methods. Journal of Physical Activity and Health. 2013;10(3):437-50.
48. Carlson JA, Jankowska MM, Meseck K, Godbole S, Natarajan L, Raab F, et al. Validity of PALMS GPS scoring of active and passive travel compared with SenseCam. Medicine & Science in Sports & Exercise. 2015;47(3):662-7.
49. Dessing D, Pierik FH, Sterkenburg RP, van Dommelen P, Maas J, de Vries SI. Schoolyard physical activity of 6–11 year old children assessed by GPS and accelerometry. International Journal of Behavioral Nutrition and Physical Activity. 2013;10(1):97.

50. Kerr J, Duncan S, Schipperijn J. Using global positioning systems in health research: a practical approach to data collection and processing. American Journal of Preventive Medicine. 2011;41(5):532-40.
51. Klinker CD, Schipperijn J, Toftager M, Kerr J, Troelsen J. When cities move children: Development of a new methodology to assess context-specific physical activity behaviour among children and adolescents using accelerometers and GPS. Health & Place. 2015;31:90-9.
52. McCrorie PR, Fenton C, Ellaway A. Combining GPS, GIS, and accelerometry to explore the physical activity and environment relationship in children and young people - a review. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1):93.
53. Ding D, Gebel K. Built environment, physical activity, and obesity: what have we learned from reviewing the literature? Health & Place. 2012;18(1):100-5.
54. Lachowycz K, Jones A. Greenspace and obesity: a systematic review of the evidence. Obesity Reviews. 2011;12(5):183-89.
55. Jones AP, Coombes EG, Griffin SJ, van Sluijs EM. Environmental supportiveness for physical activity in English schoolchildren: a study using Global Positioning Systems. International Journal of Behavioral Nutrition and Physical Activity. 2009;6(1):42.
56. Rodríguez DA, Cho G-H, Evenson KR, Conway TL, Cohen D, Ghosh-Dastidar B, et al. Out and about: association of the built environment with physical activity behaviors of adolescent females. Health & Place. 2012;18(1):55-62.
57. Troped PJ, Wilson JS, Matthews CE, Cromley EK, Melly SJ. The built environment and location-based physical activity. American Journal of Preventive Medicine. 2010;38(4):429-38.
58. Maddison R, Jiang Y, Hoorn SV, Exeter D, Mhurchu CN, Dorey E. Describing patterns of physical activity in adolescents using global positioning systems and accelerometry. Pediatric Exercise Sciences. 2010;22(3):392-407.
59. Oreskovic NM, Blossom J, Field AE, Chiang SR, Winickoff JP, Kleinman RE. Combining global positioning system and accelerometer data to determine the locations of physical activity in children. Geospatial Health. 2012;6(2):263-72.
60. Rainham DG, Bates CJ, Blanchard CM, Dummer TJ, Kirk SF, Shearer CL. Spatial classification of youth physical activity patterns. American Journal of Preventive Medicine. 2012;42(5):87-96.
61. Coombes E, van Sluijs E, Jones A. Is environmental setting associated with the intensity and duration of children's physical activity? Findings from the SPEEDY GPS study. Health & Place. 2013;20:62-5.
62. De Nazelle A, Seto E, Donaire-Gonzalez D, Mendez M, Matamala J, Nieuwenhuijsen MJ, et al. Improving estimates of air pollution exposure through ubiquitous sensing technologies. Environmental Pollution. 2013;176:92-9.

63. Chaix B, Kestens Y, Perchoux C, Karusisi N, Merlo J, Labadi K. An interactive mapping tool to assess individual mobility patterns in neighborhood studies. American Journal of Preventive Medicine. 2012;43(4):440-50.
64. McDonald NC. Children's mode choice for the school trip: the role of distance and school location in walking to school. Transportation. 2008;35(1):23-35.
65. Rodriguez DA, Cho GH, Evenson KR, Conway TL, Cohen D, Ghosh-Dastidar B, et al. Out and about: association of the built environment with physical activity behaviors of adolescent females. Health & Place. 2012;18.

CHAPTER 9

Unravelling the physical activity context: investigating context-specific physical activity patterns in transition from primary to secondary school using accelerometers, GPS, and GIS.

This chapter will be published as:

Remmers T, de Vries SI, Ettema D, Kremers SP, Thijs C. Unravelling the physical activity context: investigating context-specific physical activity patterns in transition from primary to aecondary school using accelerometers, GPS, and GIS.

Abstract

Introduction: Physical activity (PA) significantly declines from childhood to adolescence. Therefore, the transition period between primary and secondary school seems an important target period for PA promotion. Although several studies have assessed the tracking of PA over time objectively, objective information on the behavioral context in which potential changes occur is often lacking. Therefore, the aim of this study was to investigate the relationship between PA patterns and its context in the transition period between primary and secondary school to add in-depth insight in how, where, and the time-segments at which changes in PA patterns occur.
Methods: Children participated in a 7-day accelerometer- and Global Positioning System (GPS) protocol at the last year of primary- and the first year of secondary school in 's-Hertogenbosch, the Netherlands. GPS data-points were overlaid with Geographical Information Systems (GIS) data using ArcGIS 10.1 software. Contextual data was identified based on the GPS locations of individual data-points at the participant's residence, school, sports grounds, shopping centres, and other places. Also, trips in active and passive transport were identified. Multi-level linear mixed models investigating changes in children's PA patterns were fitted adjusting for age, gender, meteorological circumstances, and the nested structure of measurement-days within children and children within schools. Outcome measures were minutes spent in sedentary time, light PA and moderate-to-vigorous PA, specified for the time-segments before school, during school, after school and during weekend days.
Results: In total, 89 boys and 86 girls provided valid longitudinal data. Average age at baseline was 12.1 years. Total time spent in LPA and MVPA declined between primary and secondary school, especially after school and during weekends. Considerable declines in after school PA were found. Here, PA at other places (e.g. visiting friends or at places in the neighbourhood but outside the house) was replaced with increased sedentary time at children's residence. Transport-related activity significantly increased during weekdays over time, and stronger increases were found for children with higher increases in distance from the residence to their school between primary and secondary school.
Conclusion: LPA and MVPA especially declined after school and during weekends. Although active transport increased due to increased distance from the residence to their school, the major drivers of decreasing PA levels from primary to secondary school are 1) increased sedentary time at the residence, 2) decreased LPA at sports grounds, and 3) decreased LPA and MVPA at other locations. Studies combining accelerometers, GPS, and GIS data provide valuable information in understanding the development of context-specific PA patterns.

Introduction

Insufficient physical activity (PA) and excessive sedentary behaviour in children have been consistently linked to various detrimental short- and long term consequences for health and general wellbeing; such as overweight and obesity (1), bone health (2), and mental health (3). However, children's PA levels decline from childhood to adolescence (i.e. 8-16-year-old) (4-8).

The transition between primary and secondary school is an important phase for PA promotion as changes are likely to occur in children (e.g. biological changes and changes in perception of competence and preferences) (9), their physical environment (e.g. changes in the school environment), their social environment (e.g. classmate changes) and their learning environment (e.g. more homework). In total, four studies have longitudinally investigated this transition using subjective measurements of PA (9-12), and five studies using (partly) objective measurements of PA (13-17). In contrast to the above described studies, four additional longitudinal studies examined PA development in 9-15-year-old children, but have not explicitly investigated the change of schools (7, 18-20). Results from studies investigating the transition from primary to secondary school are mixed. For example, six studies reported a decline in PA between primary and secondary school (7, 9, 12, 17-19), while two studies reported an increase in PA in this transition period (13, 16).

In addition, previous longitudinal studies have shown that changes in PA from childhood to adolescence differs between boys and girls (4, 21). However, other studies investigating the transition to secondary school do not suggest such moderation by gender. For example, De Meester et al. (2015) found no significant gender differences in development of weekday pedometer steps and accelerometer measured moderate-to-vigorous PA (MVPA), and Jago (2012) found similar change-scores for boys and girls in a-priori gender-stratified analyses on weekday and weekend MVPA in the transition from primary to secondary school (14, 15). However, the available evidence for potential gender differences in this transitional phase to secondary school is still scarce, and additional longitudinal studies are warranted to unravel gender differences or similarities during this important transitional phase.

To be able to interpret changes in PA patterns in the transition to secondary school, information about the context (or domain) in which PA occurs is essential (e.g. home, school or organized sports participation). Most studies measured the PA context by complementing their PA-measurements with self-reported contextual data (e.g. transport mode to school) (13-15, 17). For example, three studies showed an increase in self-reported active transport from primary to secondary school (11, 15, 16), Also, several studies have suggested that change in school environments during the transition from primary to secondary school, may affect children's total PA via changes in active transport (11, 13, 17, 22). A major barrier to transport-related PA in youth is the distance between the home and school location (23, 24). Marks et al. (2015) also showed that a change of

school environment in the transition to secondary school was associated with less self-reported activity and active transport, but no differences were found on accelerometer measured daily PA (17). This is in line with numerous previous studies that showed a lack of cohesion of results from subjectively-measured versus objectively-measured PA (25).

Self-reports may be especially vulnerable to social desirability or recall bias, and may cause increased participant's burden (26, 27). However, recent studies showed that it is feasible to passively gather continuous PA and location data, by combining accelerometers and Global Positioning System (GPS) data (28). When combined with Geographical Information Systems (GIS), which holds extensive data about environmental characteristics, the physical context of specific PA patterns (or sedentary behaviour) can be inferred from the contemporaneously-measured geographical location or travel speed (29-32). For example, the study of Klinker et al. (2014) reported on age and gender differences of PA in the contexts of home, school, transport and leisure, and was also able to identify eleven additional contexts (or subdomains) based on evaluation of time-segments and GPS data (33). Consequently, studies combining accelerometers and GPS loggers may also be valuable to unravel changes in context-specific PA patterns during the transition from primary to secondary school.

Consequently, literature suggests that the effect of the transition to secondary school on PA is influenced by two factors: gender and active transport to school (13-17). However, there is insufficient evidence that these factors are indeed related to objective PA patterns, and how these factors relate to the various contexts (or domains) in which children participate. Therefore, the aims for the present study were twofold. First, we aimed to investigate the development of context-specific PA patterns in the transition from primary school towards secondary school using accelerometers, GPS loggers and GIS data. Our secondary aim was to investigate potential moderation of this relationship by gender and difference in home-school distances.

Methods

Design and participants

The present study was embedded in the PHysical Activity in public Space Environments (PHASE-kids) study, which was specifically set up to examine longitudinal relationships between characteristics of the physical environment and children's context-specific PA patterns, in the transitional phase from primary to secondary schools. Children's PA patterns were investigated at two time-points; at baseline (in the last year of primary school) and at follow-up (in the first year of secondary school). Measurements were conducted in the municipality of 's-Hertogenbosch in The Netherlands, which covers around 110 square kilometres flatland, and has approximately 150.000 residents (34) (Figure 1). Population density varies between municipality neighbourhoods (1.8 - 59.0 residents per hectare). Average population density of included neighbourhoods was 19.4 residents per hectare (35). At baseline, we invited 30 primary schools to participate (initial

sample ≈ 1000 children), of which 20 schools agreed. All children in their final year were invited to participate in a 7-day accelerometry and GPS monitoring protocol. One year later, all children changed schools. All Participating children were approached again at their secondary school for a follow-up measurement using the same protocol. Ethical approval for the PHASE-kids study was obtained from the research ethics committee of the Maastricht University Medical Centre (reference number 12-4-077).

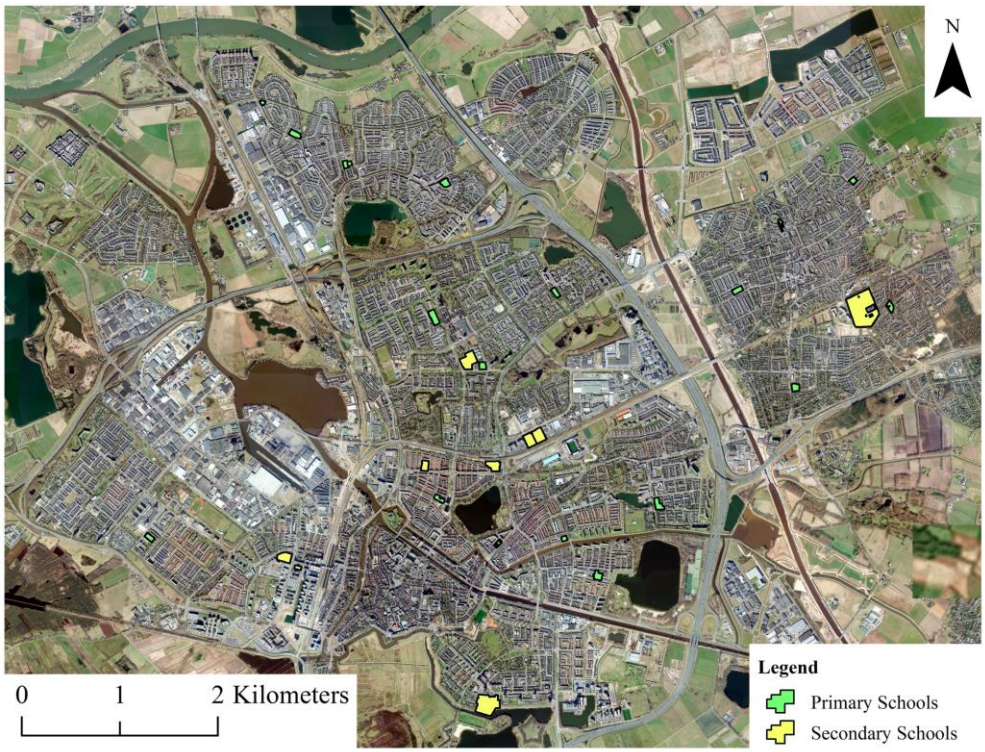


Figure 1: Geographical distribution of participating Primary and Secondary schools in the municipality of 's-Hertogenbosch, the Netherlands.

Data were collected from April till July 2015 and from April till July 2016, with an average daily temperature of 15.12 degrees Celsius (SD=4.96) and 77% of the days with < 1.0mm of precipitation (based on registries from a local weather station). Sunset times during this time-period in the centre of the Netherlands were between 20:13 and 22:06 hours (data extracted from http://www.timeanddate.com/sun/netherlands). Accelerometers and GPS loggers were distributed during school hours, where children received verbal and written instruction about how to wear the devices. Both devices were attached to the waist and worn at the right hip with a single elastic belt. Children were instructed to wear the devices during waking hours for 7 consecutive days, to only remove the belt during water-related activities (e.g. swimming, showering), and to recharge the GPS logger before going to sleep. In addition, children were asked to record the times and reasons why they took off the devices in a diary. After measurement, devices were collected by the research-staff

during school hours, while the child and one of their parents received a verbal and written invitation for an electronic questionnaire.

Measurement

Socio-demographic measures

Directly after measurement, children and parents filled in an electronic questionnaire focusing on aspects such as birthdate of the child, residential address, perceived physical and social environment, child's (travel) behaviours and homework. We assessed whether children from divorced parents were residing at two locations, and whether children potentially moved home between baseline and follow-up measurements. Schools provided detailed class timetables for the data-collection period.

Accelerometer and GPS loggers

In this study, accelerometers (GT3X, ActiGraph, Pensacola, Florida) were set to record data at 10 second epochs. Actilife version 6.11.9 was used for initialization and downloading. The GPS logger used in this study (BT-Q1000XT, Qstarz International Co, Taipei, Taiwan) showed relatively good static spatial accuracy compared to other units (36), and acceptable dynamic accuracy (37). The manufacturer's software QTravel version 1.46 was used for initialization and downloading. GPS devices were also set to record data at 10 second epochs while recording parameters such as date, time, longitude, latitude, and speed. GPS and accelerometer devices stopped logging data when storage capacity was full (33).

Data analysis

Data management

Accelerometer and GPS data were processed using the Personal Activity and Location Measurement System (PALMS), which allows users control over most parameter settings in a web-based application (32, 38). In order to handle the data-load, data were processed in PALMS separately for each school and time-point (i.e. baseline and follow-up). PALMS categorized intensity of accelerometer activity into sedentary time (ST), light PA (LPA), moderate PA (MPA), and vigorous PA (VPA) according to Evenson's cut-points (39), which performed best in free-living activities of 5-15 year-old children (40). We defined non-wear time as ≥ 20 consecutive minutes of zero counts (41). Datasets were cleaned based on extreme speed (i.e. threshold ≥ 130 kmph) and changes in elevation (i.e. threshold ≥ 1000 meters) in the GPS data. Algorithms as described in Carlson et al. (2015) were used for trip and trip mode classification (e.g. pedestrian, bicycle) from the GPS data (31). As the sample in the study of Carlson et al. (2015) consisted of commuting cyclists that were expected to accumulate higher cycling speeds, the present study deviated from these thresholds by using the 10-25 kmph bicycling speed-threshold. Invalid GPS points were imputed from the last known valid point, for up to 10 minutes. Finally, PALMS matched accelerometry and GPS data based on start- and end-times of the GPS logger.

Subsequently, we combined school-specific datasets into multiple PostgreSQL databases (http://www.postgresql.com), where we performed additional queries to identify before school (i.e. 6 AM – start school time), during school (i.e. based on individual school's schedules), and after school (i.e. end school time – 11:59 PM) time-segments. Additionally, we also extracted data on weekend days. This resulted in eight time-segmented datasets; four datasets regarding primary and four datasets regarding secondary school.

Spatial analyses

Time-segmented datasets were integrated into ArcGIS version 10.4.1 (ESRI, Redlands, California), where we overlaid GIS-data from the municipality of 's-Hertogenbosch. First, we geo-referenced the parcels for each participant's residence and school, using ArcGIS geocode-functionality and the municipality's address-database (Figure 1). For each dataset, we identified the context 'home' by selecting data-points (records) that were within 10 meters of each respondent's residential-parcel. In addition, we identified the other contexts by identifying records within 10 meters from the school parcel, sports facilities, shopping centres or malls. For the identification of active and passive transport behaviours, we applied the above-described PALMS speed-thresholds. Finally, records that were not identified in the above described categories, were defined as records at other locations (e.g. at friend's homes or at parks). These context-definitions were based on the GPS-derived contexts of Klinker et al. (2014) and the Sensewear-derived contexts of De Baere et al. (2015) (16, 33). Finally, for each respondent, we computed the crow-fly distance between home and their primary- and secondary school parcel.

Data reduction

First, we selected children with longitudinal data in the transition from primary to secondary school (Figure 2). Subsequently, we omitted data from children that moved home between baseline and follow-up measurements, and with more than one home environment (often in the case of divorced parents). From these subsamples, data-points were excluded where the accelerometer was not worn (based on $\geq$ 20 consecutive minutes of zero counts), and data-points with extremely high accelerometer counts (i.e. > 9498 counts per minute) were omitted. Subsequently, we aggregated the data-points to the daily level (Figure 2). In accordance with previous studies investigating time-segmented PA (42-44), we ensured reliability of each time-segment by only selecting records from days with $\geq$ 50% of the potential wear time. For example, for children from schools that start at 8:00 AM, potential wear time in the before school time segment is two hours (as the definition of before school time starts at 6 AM). In this way, these children were required to have at least 60 minutes of wear time in this specific time segment. Finally, baseline and follow-up data were combined in four longitudinal datasets (i.e. before school, during school, after school and weekends; Figure 2).

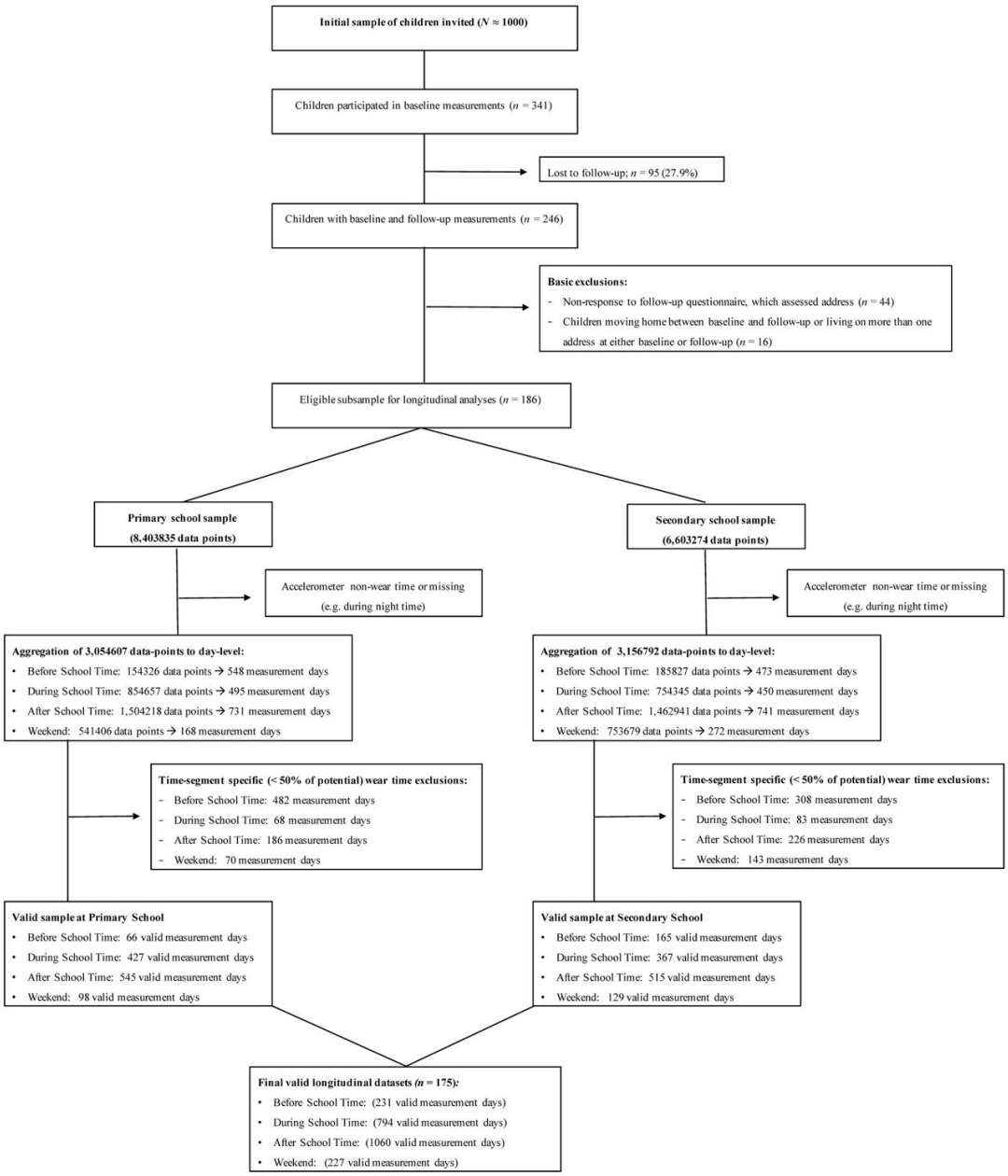


Figure 2: Data flowchart

Statistical analyses

First, descriptive statistics were performed in order to present children's general PA patterns at primary and secondary school. After describing the development of total PA in the transition between primary and secondary school, we calculated the median number of minutes for the time that children spent in context-specific LPA and MVPA activities, both in primary school and secondary school (45).

Subsequently, multi-variate analyses were performed to test whether context-specific changes significantly increased or decreased during the transition from primary to secondary school. As context-specific PA-variables showed significant differences from normality, we decided to present median parameters in our univariate descriptive analyses, and log-transformed transition coefficients in our multivariate explanatory analyses. In subsequent multivariate models, days were used as the unit of analyses and the main variables of interest was the index-variable that represented either baseline- or follow-up measurement. All multivariate analyses were performed using multilevel linear mixed models, with a repeated term for days within children and a random term for children within schools. Outcome variables were minutes of sedentary time (ST), LPA and MVPA (specified for each time-segment and context). First, we adjusted our multilevel models for context-specific wear time, gender, and age. In addition, based on registries from local weather stations, we extracted hourly meteorological data for each day of PA measurement. We computed daily averages of meteorological data between 6 AM and 8 PM (as only during these times it would potentially affect children's behaviours), and we adjusted for these meteorological variables in the second set of analyses.

Model fit and normality of residuals of these models were inspected to verify its fitting capabilities. Some contexts consisted of very few data-points (e.g. during school time at shopping centres). In order to refrain from presenting underpowered and under-fitted results, 1) non-significant covariates ($p > 0.05$) were deleted from models, and 2) contexts with a median of less than 5 minutes of data and performed for less than 50 days were not presented in subsequent analyses. We also tested for moderation-mechanisms in our models. First, we investigated moderation of gender by computing interaction terms (i.e. gender*transition coefficient) and inspecting results for boys and girls separately. Likewise, we also investigated moderation of the difference in distance from home to primary school versus home to secondary school (hereafter referred as difference in home-school distance) on the development of PA patterns in the transition from primary to secondary school. In subsequent analyses, stratum specific associations were performed after computing a median split of home-school differences (median = 2215 meters). Statistical analyses were performed using SPSS 21.0 for Windows (IBM SPSS Inc., Armonk, NY), and $p < 0.05$ indicated statistical significance.

Results

Participant characteristics and development of total PA

In total, 89 boys and 86 girls from 19 primary and 10 secondary schools provided valid data. Children were averagely aged 12.1 (SD=0.44) years old at baseline. Results from an electronic questionnaire administered directly after accelerometry (response rate 77% and 75% for the children and parents, respectively), showed that parents from participating children had relatively high socio-economic status; 72% with secondary vocational or higher educational diploma, and 67.9% with a paid job for at least three days per week. On average, children lived 620 (SD=571) meters from their primary school, and 3127 (SD=1976) meters from their secondary school. The distance of children's home to their secondary school is on average 2506 meters further (SD=2014), compared to the distance to their primary school.

In Table 1, we describe the change of total PA from primary to secondary school. It can be observed that LPA and MVPA increased before school time from primary to secondary school. In contrast, considerable declines were found after school and in weekend days. At baseline, girls seemed to be less active during school time compared to boys. However, after school, girls spent more time in LPA, whereas boys spent more time in MVPA. At follow-up boys spent more MVPA minutes at school and after school, whereas girls spent more LPA minutes before school and after school. Sedentary time increased during all time-segments except before school (Table 1).

Table 1: Development of total PA in the Transition between Primary and Secondary School

	Baseline minutes per day (Primary School)			Follow-up minutes per day (Secondary School)			Change in minutes ST (SD)	Change in minutes LPA (SD)	Change in minutes MVPA (SD)
	Mean ST (SD)	Mean LPA (SD)	Mean MVPA (SD)	Mean ST (SD)	Mean LPA (SD)	Mean MVPA (SD)			
Week days Before School Time	44.1 (13.6)	42.5 (9.4)	2.7 (3.2)[1]	46.04 (18.9)[1]	48.8 (14.9)[2]	4.0 (5.8)	1.9 (2.6)	6.3 (2.0)	1.3 (0.9)
Week days During School Time	192.6 (55.9)[2]	114.6 (46.3)[1]	15.5 (13.7)[1]	208.8 (59.7)	107.2 (42.8)	13.6 (19.4)[1]	16.2 (4.1)	-7.4 (3.2)	-1.9 (1.3)
Week days After School Time	198.6 (69.9)	175.7 (56.2)[2]	27.7 (24.2)[1]	239.7 (71.1)[1]	156.3 (55.0)[2]	19.3 (23.3)[1]	42.2 (4.3)	-19.4 (3.4)	-8.4 (1.5)
Weekend days	331.9 (82.4)	317.9 (87.1)	56.2 (48.4)	384.9 (93.5)	272.6 (94.9)	35.7 (34.8)	53.0 (11.9)	-45.2 (12.3)	-20.6 (5.6)

[1]: significantly higher for boys compared to girls. [2]: significantly higher for girls compared to boys

Context-specific PA patterns in Primary and Secondary School

The vast majority of time spent in primary and secondary school was at the residence, except during school time (Table 2). During school hours, one can still observe time spent at the residence, in active transport and at other locations (e.g. at friend's homes or at parks). Besides potential irregularities in school schedules, these minutes may reflect afternoon breaks or structured physical education classes, in which children are allowed off the school parcel. Likewise, some time was spent at school grounds during the afterschool time-segment, which may reflect schoolyard activity or some extra-curricular activities (Table 2). Especially after school and in weekends, children also spent time at other locations. This may reflect activities such as visiting friends, or playing at neighbourhood playgrounds.

In general, at primary school, the majority of MVPA minutes during weekdays was spent at sports grounds. In weekends this was still the case, but now active transport and activities performed at other locations (e.g. at friend's homes or at parks) also contributed to total MVPA (Table 2). When comparing median minutes of LPA and MVPA at secondary- versus primary school, the following was observed: first, children increased their LPA in active transport especially before and during school hours. Second, during school hours, children spent fewer minutes of LPA at school grounds, but more LPA at other locations. Thirdly, time at sports grounds (especially LPA minutes) tend to decline, both after school and in weekends. Fourth, LPA minutes spent after school at other locations declined. Finally, in weekends, minutes of LPA and MVPA at the residence and at other locations also tended to decline, while sedentary time at the residence increased. We generally found that MVPA was higher for boys than girls in various contexts. For example, in primary school, boys performed significantly more MVPA at school grounds before school, during school, and after school. In addition, in primary and secondary school, boys spent significantly more time in MVPA at other locations after school (Table 2).

Table 2: Median minutes of context-specific Physical Activity Patterns at Primary and Secondary School

	Before School time (daily median minutes)						During School Time (daily median minutes)						After School Time (daily median minutes)						Weekend days (daily median minutes)					
	Primary School			Secondary School			Primary School			Secondary School			Primary School			Secondary School			Primary School			Secondary School		
	ST	LPA	MVPA	ST	LPA	MVPA	ST	LPA	MVPA	ST	LPA	MVPA	ST	LPA	MVPA	ST	LPA	MVPA	ST	LPA	MVPA	ST	LPA	MVPA
Residence	28.7	27.3	1.0	24.3	22.6	1.0	24.0	10.8	0.7	18.0	11.5	1.0	112.3	70.3	2.5	166.0	78.3	2.2	164.5	137.2	6.7	189.3	124.2	3.7
School grounds	3.2	6.3	1.0	7.9	7.3	1.0	167.7	83.5	5.5 [1]	145.8	65.6	4.0	2.3	6.0	1.2 [1]	5.3	6.8	2.0	0.7	0.3	4.0	0.2	0.2	0.2
Sports grounds	4.7	0.3	0.4	0.5	1.0	0.75	8.0	9.2 [3]	11.8	5.3	5.0	11.8	6.7	13.5	13.0 [1]	5.5	1.2	10.3	15.3	21.8	14.5	11.0	5.4	16.0
Shopping centres	1.2	0.3	2.3	1.0	2.0	0.7	1.2	1.9	1.0	1.0	2.3	1.8	3.8	4.2	2.0	2.8	4.2	2.0	10.6	19.1[1]	6.0	8.8	9.2	5.0
Active transport	1.4	3.8	1.0	2.0	10.7	2.2	2.5	4.7	3.3	2.8	10.5	2.0	3.0	11.3	5.0	3.2	13.5	4.0	3.9	12.0	8.8	1.0	9.5	10.0
Passive transport	3.9	3.5	0.0	7.7	3.5	0.0	3.5	3.9	0.5	2.0	4.0	0.8	9.1	7.8	0.7	10.4	8.0	0.8	17.2	15.4	1.0	15.8	12.5	1.0
Other locations	4.8	3.3	0.8	4.0	3.7	0.7	8.8	7.7	2.5	27.6	15.2	1.3	42.7	39.8	4.8 [1]	30.0	20.0	2.3 [1]	91.0	88.5[2]	12.5	89.8	79.0	7.0

[1]: significantly higher for boys vs. girls (p <0.05). [2]: significantly lower for boys vs. girls (p <0.05). Gender differences were investigated using multilevel linear mixed models, adjusting for context-specific wear time, age, meteorological circumstances, and nested structure of days within children and children within schools. Children that did not participate in a specific context did not contribute to the calculation of the median minutes.

Development of context-specific PA patterns in transition between primary and secondary school

When observing the log-transformed adjusted coefficients representing change to secondary school, the following can be observed. Before school, we found statistically significant increases in sedentary time at school grounds (probably due to earlier arrivals at school). In addition, we found increases of LPA minutes before school in active transport (Table 3). These increases were also seen during school (outside the school parcel) and after school hours. During school hours, we found a decline of LPA at the school parcel. Sedentary time at the school parcel also decreased whereas sedentary time and LPA minutes at other locations increased considerably. This may collectively mean that the minutes at the school ground during school hours decreased, and that this was replaced by minutes at other locations outside the school's parcel. Also, in contrast to the results presented in Table 2, adjusted models showed an increase of MVPA at sports grounds during school hours. With regard to the afterschool time, we found a decline of after school LPA at other locations. This was replaced by increases in sedentary time at the residence (Table 3). Finally, in weekends, we found non-significant but considerable decreases of LPA at sports grounds. As this was not replaced by sedentary time or MVPA, this could mean that children tend to spend less time at sports grounds.

We also found some results that showed significant differences by gender. First, minutes of MVPA spent at shopping centres increased during weekends in the transition from primary to secondary school, which was significantly stronger for girls compared to boys (i.e. transition coefficient = 0.55 (p <0.05) and -0.07 (p >0.05) for girls and boys, respectively). Second, we found a decline of MVPA minutes spent at school grounds between primary and secondary school, which was stronger for boys compared to girls (i.e. transition coefficient = -0.24 (p <0.05) and -0.05 (p >0.05) for boys and girls, respectively).

Table 3: Development of context-specific patterns of Physical Activity and Sedentary Time within the Transition from Primary to Secondary School

Transition (follow-up versus baseline)	Before School Time (log-transformed change in daily minutes)			During School Time (log-transformed change in daily minutes)			After School Time (log-transformed change in daily minutes)			During Weekend Days (log-transformed change in daily minutes)		
	ST	LPA	MVPA	ST	LPA	MVPA	ST	LPA	MVPA	ST	LPA	MVPA
Residence	-0.11	-0.05	[1]	**-0.19**	0.04	[1]	**0.13**	0.03	[1]	0.09	-0.02	-0.14
School grounds	**0.31**	0.07	[1]	**-0.09**	**-0.11**	-0.07 [2]	[1]	[1]	[1]	[1]	[1]	[1]
Sports grounds	[1]	[1]	[1]	-0.16	-0.29	**0.38**	-0.14	-0.20 [3]	0.20	-0.06	-0.61 [3]	-0.18
Shopping centres	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	-0.06	-0.06	**0.47** [2]
Active transport	[1]	**0.42** [3]	[1]	[1]	**0.37** [3]	[1]	[1]	**0.22** [3]	0.03	[1]	-0.08 [3]	-0.08
Passive transport	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	-0.14	**-0.23**	[1]
Other locations	[1]	[1]	[1]	**0.38**	**0.20**	[1]	**-0.18**	**-0.14**	0.07	-0.06	-0.12	-0.07

Multivariate linear mixed models, adjusted for age, gender, period-specific wear time (e.g. after school), meteorological variables, difference in distance between home and school (follow-up vs. baseline), and the nested structure of days within children and children within schools. Dependent variables are log-transformed minutes of ST, LPA and MVPA in each context. Bold numbers represent statistical significance at $p < 0.05$. [1]: too few data points to calculate multivariate model (see Table 2). [2]: statistical significantly interaction, indicating moderation of gender ($p < 0.05$). [4]: association significantly stronger for children with larger difference between in distance home and school (follow-up vs. baseline; $p < 0.05$). [5]: association significantly stronger for children with smaller difference between in distance home and school (follow-up vs. baseline; $p < 0.05$).

The influence of distance to school on the development of PA patterns

Results in Table 4 show that children with higher home-school distance differences (i.e. difference in distance from home to primary school versus home to secondary school) showed higher increases in transport-related LPA before, during, and after school hours between primary and secondary school. This means that increased transport-related LPA is due to the increased distance from home to school. In addition, we found that children with larger home-school differences were less likely to reduce minutes of LPA in active transport during weekends between primary and secondary school, compared to children with smaller home-school differences (Table 4).

Table 4 demonstrates steeper declines of after school LPA at sports grounds for children with higher differences in home-school distances. Although in children with smaller home-school differences LPA and MVPA at sports grounds also declined, we cautiously suggest that children with larger home-school differences may have been more likely to decrease their activities at sports grounds during weekends, as a compensation of their increased transport-related activity during weekdays. To further test this assumption, we investigated whether children with higher increases in home-school distances performed more total PA, but we found no such moderation mechanism on total ST, LPA and MVPA.

Table 4: Moderation by the distance between Home and Primary School versus the distance between Home and Secondary School, in the development of context-specific patterns of Sedentary Time and Physical Activity

Stratum-specific associations of transition-coefficient (follow-up versus baseline) by difference in home-school distance (at follow-up versus baseline)		Before School Time (change in daily minutes)			During School Time (change in daily minutes)			After School Time (change in daily minutes)			During Weekend Days (change in daily minutes)		
		ST	LPA	MVPA	ST	LPA	MVPA	ST	LPA	MVPA	ST	LPA	MVPA
Sports grounds	Smaller difference in home-school distance [2]	[1]	[1]	[1]	[1]	[1]	[1]	-0.10	-0.001 [4]	0.20	-0.54	-0.38 [4]	-0.49
	Larger difference in home-school distance [3]	[1]	[1]	[1]	[1]	[1]	[1]	-0.18	-0.43 [4]	0.12	-0.43	-0.53 [4]	-0.56
Active transport	Smaller difference in home-school distance [2]	[1]	**0.25** [4]	0.23	[1]	0.13 [4]	-0.04	[1]	0.05 [4]	0.04	[1]	-0.12 [4]	-0.24
	Larger difference in home-school distance [3]	[1]	**0.66** [4]	**0.57**	[1]	**0.58** [4]	-0.19	[1]	**0.38** [4]	0.05	[1]	-0.001 [4]	0.10

Multivariate linear mixed models, adjusted for age, gender, period-specific wear time (e.g. after school), meteorological circumstances, and the nested structure of days within children and children within schools. Dependent variables are log-transformed minutes of ST, LPA and MVPA in each context. Bold numbers represent statistically significant stratum-specific associations (p <0.05). [1]: no statistically significant moderation found (p ≥0.05), or too few data points to calculate multivariate model. [2]: distance from home to secondary school is 2091 meters closer until 2215 meters further than distance from home to primary school. [3]: distance from home to secondary school is 2258 meters further until 11452 meters further than distance from home to primary school. [4]: statistically significant interaction between strata (p <0.05).

Discussion

This was the first study to use combined accelerometer, GPS and GIS data to investigate the longitudinal associations between PA patterns and its context in the transitional phase from primary to secondary school. Building upon the evidence from earlier studies showing a decline of PA in the transition from childhood to adolescence (4-7, 17-19), this study adds in-depth insight of where and during which time-segment during the day these declines occur.

Several results were in line with findings of previous studies. First, in line with self-reported increases in overall transport-related PA in transition to secondary school (11, 13, 15, 16), we also found significant increases in active transport before-, during-, and after school in the transition phase from primary to secondary school. Also, in line with three studies (13, 22, 23), we found that this increase was a result of the increased distance between home and school. Namely, transport-related activity during weekdays increased significantly more in children with larger home-school differences. Among a relatively younger but otherwise comparable Dutch sample Dessing et al. (2014) found that when the distance between home and primary school exceeded 900 meters, probability of using passive transport was >50% (average distance from home to school in this study was 364 meters, compared to the present study average of 620 meters) (23). These findings are not in line with the present study, as we showed that when transitioning to secondary school, children that were facing bigger distances to their school did not spend significantly more time in passive transport (average distance from home to secondary school was 3127 meters). This may be due to the increased responsibility parents provide these children at older ages. Future studies are encouraged to replicate these designs in other geographical and cultural contexts.

Secondly, we found that total LPA and MVPA during school time was relatively stable over time, which supports conclusions of a 4-year follow-up study of Brooke et al. (2014) (19), but contrasts results from the 3-year follow-up study of Harding et al. (2015) (18) who reported parallel decreases of LPA during school, after school, and in weekends in the transition phase between primary and secondary school. Also, the number of minutes spent in MVPA during school hours was comparable with two previous studies (16, 46). More specifically, we found that after the transition less sedentary and LPA time was spent at the school-parcel. This was replaced by sedentary time at home and other locations. Emerging evidence links daily PA and active breaks to academic performance (47-49), and this may provide schools with opportunities for increasing PA (and thus also improving academic performance) during school hours, for example by high quality physical education lessons. Moreover, parents and health promotors are also encouraged to provide infrastructure to prevent prolonged sedentary time at home, for example by active videogames or social activities.

Third, we found that total after school LPA and MVPA declined in the transition period, which supports conclusions from three studies (14, 18, 19). Also, in line with these three studies that suggested increased self-reported time spent on homework, leisure time TV and computer use in transition to secondary school (15-17), the present study showed that changes in after school PA were predominantly due to a decrease of PA performed at other locations (e.g. at friend's homes or at parks), and replaced by an increase in sedentary time at the residence. In addition, in line with two studies with a longer follow-up period (18, 19), but in contrast to one study that also investigated the one-year transition period (14) we found that average LPA and MVPA declined in weekends.

Fourth, an additional aim of this present study was to investigate potential moderation of gender on the context-specific PA patterns in transition to secondary school. Although we generally found that MVPA in various contexts was higher in boys, we found only two significantly different transition coefficients. Namely, girls showed stronger increases of MVPA at shopping centres during weekends than boys in the transition period, while boys showed stronger declines of MVPA spent at school grounds than girls. The latter may be influenced by boys' considerably higher baseline MVPA at school grounds. Comparable studies investigating the specific one-year transition to secondary school found no gender differences (14-16), while other studies investigating the broader transition to adolescence (using longer follow-up periods) generally did find significant gender differences (4, 7, 19). This may mean that, although the present study indicated that there may be some gender differences at the residence and at other locations during weekends, the relatively short one-year follow-up period may be too short to detect significant gender differences in the development of PA patterns in other physical or behavioural contexts.

Although we demonstrated considerable increases of transport-related LPA before-, during-, and after school in the transition phase, we found declines of active transport in weekends. Moreover, moderation analyses revealed that children with larger home-school differences (and thus more active transport during weekdays) tended to better maintain activity-related transport in weekends. We cautiously suggest that children with increased transport-related activity during weekdays (as a result of increased home-school difference) may have compensated this with declines of LPA at sports grounds after school and during weekends. Previous studies suggested that such compensation does not occur within children and within one day (13, 17, 23), contributing to the so-called "active synergy" hypothesis (22). Another study indicated that compensation within children of LPA and MVPA at the following day might occur when accounting for children's person-level activity (50), contributing to the so-called "activitystat" hypothesis (51, 52). However, investigating compensatory mechanisms was not the primary purpose of this paper, future research using more sophisticated within-person experimental designs and larger samples are needed to unravel compensation mechanisms in context-specific PA patterns. In the present study, sensitivity-analyses suggested that children with higher PA-levels at baseline were more likely to show a subsequent decline towards secondary school (data not shown).

Strengths and weaknesss

Study strengths are the utilization of GPS devices in order to investigate associations between the objectively assessed context-specific PA patterns (using GIS and GPS), adjusting for meteorological differences and the multilevel structure. However, this study also had some weaknesses. First, in order to reduce complexity of associations, analyses were conducted on a subsample (i.e. non-movers and living at a single address). Due to period-specific wear time validation criteria, the amount of measurement-days in our analyses was further reduced. The latter may be because children experienced the devices as uncomfortable or unfashionable. Although innovations to facilitate application of smaller and more comfortable devices are fast developing, extensive validations of performance both in PA- and location assessment are warranted. Attrition analyses revealed the same patterns as described in Table 1, with a decrease of LPA and MVPA in all segments except before school time. Second, when our definition of time-segments is compared to other studies, especially the time-segment during school may have been improved by additionally defining recess time (19, 53). However, as in our current analyses some associations could not be analysed due to limited data-points (e.g. such as activity at shopping centres), researchers are encouraged to balance specificity of time-segments and available data-points adequately. We found that during school hours, children spent considerable time outside school grounds (e.g. in active transport). This was unexpected, and may reflect activities in-between classes, activities during recess, or trips to externally located physical education facilities. Finally, although we were able to identify active transportation trips based on the GPS signal (i.e. walking and cycling), hip-worn Actigraph GT3X+ accelerometers may still have underestimated the workload of cycling trips (54).

External validity

Findings of this study may be generalizable to samples with comparable distances from children's residences to their primary- and secondary schools, similar school regimes and similar motives or regulations for active transport. For example, in the Netherlands, there are no organized passive transport programs in place (e.g. school busses) and the environment is generally supportive for active transport (e.g. absence of hills, high availability and quality of cycling paths, bike sheds at schools). This may increase the likelihood of active transport in the home-school commute, regardless of the distance between home and school. Children's or parental motives regarding PA, parental educational levels, and meteorological opportunities (due to hours of daylight) may be different from other international samples (55). In addition, time-constrains of children due to competing activities such as organized sports participation or homework may also be considered in comparing results with other studies.

Conclusion

This study investigated longitudinal changes of PA patterns in its context in an important phase of children's PA development. This study contributed to the existing literature by investigating objectively measured- and context-specific PA patterns in the transition from primary to secondary school. Furthermore, given the importance of this transition-period for the development of long-term PA patterns, revealing relevant and changeable contexts, may aid in developing and focusing future PA interventions. Consistent with previous literature (4, 17-19), we found considerable declines in PA after school and in weekends in the transition phase. Declines in after school PA were predominantly caused by increased sedentary behaviour at their residence. Declines in PA during weekends were probably influenced by decreases of active transport and PA at other locations. On the other hand, increases were found in weekday active transport, which was related to increased distance between children's residence and their school.

Acknowledgements

This study was funded by the Netherlands Organization for Scientific Research (NWO). We would like to thank Menno Slingerlands in assisting in the study design. In addition, authors would like to thank Peter Kool and the municipality of 's-Hertogenbosch in facilitating this study. Authors acknowledge the assistance of Tim Schepers, Marieke Obbes and Veerle van den Heuvel in the measurements. Finally, we would like to thank participating schools, children and parents.

References

1. Strong WB, Malina RM, Blimkie CJ, Daniels SR, Dishman RK, Gutin B, et al. Evidence based physical activity for school-age youth. The Journal of Pediatrics. 2005;146(6):732-7.
2. Boreham CAG, McKay HA. Physical activity in childhood and bone health. British Journal of Sports Medicine. 2011;45.
3. Biddle SJ, Asare M. Physical activity and mental health in children and adolescents: a review of reviews. British Journal of Sports Medicine. 2011;45:886-896.
4. Telama R. Tracking of Physical Activity from Childhood to Adulthood: A Review. Obesity Facts. 2009;2(3):187-95.
5. Kristensen PL, Møller N, Korsholm L, Wedderkopp N, Andersen LB, Froberg K. Tracking of objectively measured physical activity from childhood to adolescence: the European youth heart study. Scandinavian Journal of Medicine & Science in Sports. 2008;18(2):171-8.
6. Nader PR, Bradley RH, Houts RM, McRitchie SL, O'Brien M. Moderate-to-vigorous physical activity from ages 9 to 15 years. The Journal of the American Medical Association. 2008;300(3):295-305.

7. Corder K, Sharp SJ, Atkin AJ, Griffin SJ, Jones AP, Ekelund U, et al. Change in objectively measured physical activity during the transition to adolescence. British Journal of Sports Medicine. 2013(0):1-8.
8. Dumith SC, Gigante DP, Domingues MR, Kohl HW. Physical activity change during adolescence: a systematic review and a pooled analysis. International Journal of Epidemiology. 2011;40(3):685-98.
9. Niven A, Fawkner S, Knowles A, Henretty J. From primary to secondary school: changes in Scottish girls' physical activity and the influence of maturation and perceptions of competence. Edinburgh: Teenactive Research Group, School of Life Sciences Heriot Watt University. 2009.
10. Rutten C, Boen F, Seghers J. Changes in physical activity and sedentary behavior during the transition from elementary to secondary school. Journal of Physical Activity and Health. 2014;11(8):1607-13.
11. Cardon GM, Maes LR, Haerens LL, De Bourdeaudhuij IM. Bicycling to school during the transition from childhood into adolescence: a six-year longitudinal study. Pediatric Exercise Science. 2012;24(3):369-83.
12. Inchley JC, Kirby JLM, Currie C. Physical Activity in Scottish Schoolchildren (PASS) Project: physical activity among adolescents in Scotland: final report of the PASS study. Edinburgh: Child and Adolescent Health Research Unit (CAHRU): The University of Edinburgh. 2008.
13. Cooper AR, Jago R, Southward EF, Page AS. Active travel and physical activity across the school transition: the PEACH Project. Medicine & Science in Sports & Exercise. 2012;44(10):1890-7.
14. Jago R, Page AS, Cooper AR. Friends and physical activity during the transition from primary to secondary school. Medicine & Science in Sports & Exercise. 2012;44(1):111-7.
15. De Meester F, Van Dyck D, De Bourdeaudhuij I, Deforche B, Cardon G. Changes in physical activity during the transition from primary to secondary school in Belgian children: what is the role of the school environment? BMC Public Health. 2014(14):261.
16. De Baere S, Lefevre J, De Martelaer K, Philippaerts R, Seghers J. Temporal patterns of physical activity and sedentary behavior in 10–14 year-old children on weekdays. BMC Public Health. 2015;15(1):791.
17. Marks J, Barnett LM, Strugnell C, Allender S. Changing from primary to secondary school highlights opportunities for school environment interventions aiming to increase physical activity and reduce sedentary behaviour: a longitudinal cohort study. International Journal of Behavioral Nutrition and Physical Activity. 2015;12(1):59.
18. Harding SK, Page AS, Falconer C, Cooper AR. Longitudinal changes in sedentary time and physical activity during adolescence. International Journal of Behavioral Nutrition and Physical Activity. 2015;12(1):44.
19. Brooke HL, Atkin AJ, Corder K, Ekelund U, van Sluijs EM. Changes in time-segment specific physical activity between ages 10 and 14 years: A

longitudinal observational study. Journal of Science and Medicine in Sport. 2014;19(1):29-34.
20. Morton KL, Corder K, Suhrcke M, Harrison F, Jones AP, van Sluijs EMF, et al. School polices, programmes and facilities, and objectively measured sedentary time, LPA and MVPA: associations in secondary school and over the transition from primary to secondary school. International Journal of Behavioral Nutrition and Physical Activity. 2016;13(1):54.
21. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJ, Martin BW, et al. Correlates of physical activity: why are some people physically active and others not? The Lancet. 2012;380(9838):258-71.
22. Goodman A, Mackett RL, Paskins J. Activity compensation and activity synergy in British 8–13year olds. Preventive Medicine. 2011;53(4):293-8.
23. Dessing D, de Vries SI, Graham JM, Pierik FH. Active transport between home and school assessed with GPS: a cross-sectional study among Dutch elementary school children. BMC Public Health. 2014;14(1):227.
24. Carver A, Timperio A, Crawford D. Parental chauffeurs: what drives their transport choice? Journal of Transport Geography. 2013;26:72-7.
25. Prince SA, Adamo KB, Hamel ME, Hardt J, Gorber SC, Tremblay M. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. International Journal of Behavioral Nutrition and Physical Activity. 2008;5(1):56.
26. Epstein LH, Paluch RA, Coleman KJ, Vito D, Anderson K. Determinants of physical activity in obese children assessed by accelerometer and self-report. Medicine & Science in Sports & Exercise. 1996;28(9):1157-64.
27. Sallis JF, Saelens BE. Assessment of physical activity by self-report: status, limitations, and future directions. Research Quarterly for Exercise and Sport. 2000;71(2):1-14.
28. McCrorie PR, Fenton C, Ellaway A. Combining GPS, GIS, and accelerometry to explore the physical activity and environment relationship in children and young people - a review. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1):93.
29. Chaix B, Meline J, Duncan S, Merrien C, Karusisi N, Perchoux C, et al. GPS tracking in neighborhood and health studies: a step forward for environmental exposure assessment, a step backward for causal inference? Health & Place. 2013;21:46-51.
30. Jankowska MM, Schipperijn J, Kerr J. A framework for using GPS data in physical activity and sedentary behavior studies. Exercise and Sport Sciences Reviews. 2015;43(1):48.
31. Carlson JA, Jankowska MM, Meseck K, Godbole S, Natarajan L, Raab F, et al. Validity of PALMS GPS scoring of active and passive travel compared with SenseCam. Medicine & Science in Sports & Exercise. 2015;47(3):662-7.
32. Kerr J, Norman G, Godbole S, Raab F, Demchak B, Patrick K. Validating GPS data with the PALMS system to detect different active transportation modes. Medicine & Science in Sports & Exercise. 2012;44:647.

33. Klinker C, Schipperijn J, Kerr J, Ersbøll A, Troelsen J. Context-Specific Outdoor Time and Physical Activity among School-Children Across Gender and Age: Using Accelerometers and GPS to Advance Methods. Frontiers in Public Health. 2014;2(20).
34. CBS Statline: Statistics Netherlands. Education level in the Netherlands the Hague 2017 Available from: https://www.volksgezondheidenzorg.info/onderwerp/sociaal economische-status/cijfers-context/opleiding - node-opleidingsniveau-naar-leeftijd.
35. Department of Research and Statistics. Population and area. Statistical yearbook 2015-2016: Municipality of 's-Hertogenbosch; 2016.
36. Duncan S, Stewart TI, Oliver M, Mavoa S, MacRae D, Badland HM, et al. Portable Global Positioning System Receivers: Static Validity and Environmental Conditions. American Journal of Preventive Medicine. 2013;44(2):19-29.
37. Schipperijn J, Kerr J, Duncan S, Madsen T, Klinker CD, Troelsen J. Dynamic Accuracy of GPS Receivers for Use in Health Research: A Novel Method to Assess GPS Accuracy in Real-World Settings. Frontiers in Public Health. 2014;2:21
38. The Physical Acitivty and Location Management (PALMS). 2017 [cited 2017 1st of March]. Available from: https://palms.ucsd.edu:8443/PALMS/.
39. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. Journal of Sports Sciences. 2008;26(14):1557-65.
40. Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. Medicine & Science in Sports & Exercise. 2011;43(7):1360-8.
41. Cain KL, Sallis JF, Conway TL, Van Dyck D, Calhoon L. Using accelerometers in youth physical activity studies: a review of methods. Journal of Physical Activity and Health. 2013;10(3):437-50.
42. Remmers T, Van Kann D, Thijs C, de Vries S, Kremers S. Playability of school-environments and after-school physical activity among 8–11 year-old children: specificity of time and place. International Journal of Behavioral Nutrition and Physical Activity. 2016;13(1):82.
43. Cooper AR, Page AS, Wheeler BW, Hillsdon M, Griew P, Jago R. Patterns of GPS measured time outdoors after school and objective physical activity in English children: the PEACH project. International Journal of Behavioral Nutrition and Physical Activity. 2010;7(1):31.
44. Arundell L, Ridgers ND, Veitch J, Salmon J, Hinkley T, Timperio A. 5-year changes in afterschool physical activity and sedentary behavior. American Journal of Preventive Medicine. 2013;44(6):605-11.
45. Klinker CD, Schipperijn J, Toftager M, Kerr J, Troelsen J. When cities move children: Development of a new methodology to assess context-specific physical activity behaviour among children and adolescents using accelerometers and GPS. Health & Place. 2015;31:90-9.

46. Van Stralen MM, Yildirim M, Wulp A, Velde SJ, Verloigne M, Doessegger A. Measured sedentary time and physical activity during the school day of European 10- to 12-year-old children: the ENERGY project. Journal of Science and Medicine in Sport. 2014;17(2):201-6.
47. Ahamed Y, Macdonald H, Reed K, Naylor P-J, Liu-Ambrose T, Mckay H. School-based physical activity does not compromise children's academic performance. Medicine & Science in Sports & Exercise. 2007;39(2):371-6.
48. Dwyer T, Sallis JF, Blizzard L, Lazarus R, Dean K. Relation of academic performance to physical activity and fitness in children. Pediatric Exercise Science. 2001;13(3):225-37.
49. Trudeau F, Shephard RJ. Physical education, school physical activity, school sports and academic performance. International Journal of Behavioral Nutrition and Physical Activity. 2008;5(1):10.
50. Ridgers ND, Timperio A, Cerin E, Salmon J. Compensation of physical activity and sedentary time in primary school children. Medicine & Science in Sports & Exercise. 2014;46(8):1564.
51. Rowland TW. The biological basis of physical activity. Medicine & Science in Sports & Exercise. 1998;30(3):392-9.
52. Gomersall SR, Rowlands AV, English C, Maher C, Olds TS. The ActivityStat Hypothesis. Sports Medicine. 2013;43(2):135-49.
53. Ridgers ND, Salmon J, Parrish AM, Stanley RM, Okely AD. Physical activity during school recess: a systematic review. American Journal of Preventive Medicine. 2012;43.
54. Treuth MS, Schmitz K, Catellier DJ, McMurray RG, Murray DM, Almeida MJ, et al. Defining accelerometer thresholds for activity intensities in adolescent girls. Medicine & Science in Sports & Exercise. 2004;36(7):1259.
55. Trost SG, Owen N, Bauman AE, Sallis JF, Brown W. Correlates of adults' participation in physical activity: review and update. Medicine & Science in Sports & Exercise. 2002;34(12):1996-2001.

CHAPTER 10

General discussion

The primary aim of this thesis was to increase our understanding of the relationship between environmental determinants and PA in childhood and adolescence. The different studies that have been conducted focused on either outside play, afterschool PA, total PA on weekdays and weekends, afterschool active transport, and PA patterns in the transition between primary and secondary school. Environmental determinants have been measured subjectively and objectively. Two studies used parental reports of the perceived environment, while four studies examined the environment objectively using systematic neighborhood audits, meteorological registries, or GPS and GIS methodologies. Additionally, this thesis also aimed to study the relationship between PA and the development of Body Mass Index, and in another study we focused on PA enjoyment as a potential individual-level determinant of PA behavior. After discussing the main findings from the eight studies, this chapter subsequently focuses on methodological- and theoretical considerations. Hereafter, recommendations for both practice and future studies are described.

Main Findings

Relationship between PA and the Development of Body Mass Index

Chapter 2 addresses the first aim of this thesis and describes a prospective longitudinal study on the relationship PA and development of Body Mass Index in 4-9-year-old children of the KOALA Birth Cohort Study. PA levels were studied using accelerometers at ages 5 and 7 years. Height and weight were measured at ages 5, 7, and 9 years and presented as standardized BMI scores, calculated from reference values from the Fourth Dutch Growth study (1). Analyses were stratified for gender and baseline weight status, as increments of PA may have a bigger impact on children who were overweight at baseline. Results showed that in heavier boys and girls, an increment of 6.5 minutes of MVPA with a minimum of three measurement days was associated with a subsequent significant decrease of 0.03 standard deviation BMI scores. In normal weight boys, an increment in MVPA was associated with lower BMI standard deviation scores. These findings underline that promoting MVPA in heavier boys and girls should remain a major health promotion priority in 4-9-year-old children.

PA Enjoyment and PA Behavior

Chapter 3 addresses this thesis' second aim: investigating individual-level determinants of PA in children. This chapter describes a cross-sectional study on potential moderators of the relationship between PA enjoyment and PA in 9-year-old children. In this study, PA enjoyment was self-reported using the validated 14-item PACES questionnaire (2), while PA was measured using accelerometers. Linear regression models were fitted, and moderation in this relationship was explored for gender, age, BMI, and impulsivity. A significant three-way interaction (i.e. PA enjoyment x gender x impulsivity) was found. This means that in boys, impulsivity strengthened the relationship between PA enjoyment and PA behavior, whereas in girls, impulsivity weakened this relationship. Both gender

and personality factors together moderate the relationship between PA enjoyment and PA behavior in children. This is in line with the proposed pathways of the EnRG framework (3).

Environmental Determinants of Outside Play

Chapters 4 and 5 address the third aim of this thesis: investigating relationships between perceived environment and outside play. These chapters describe two large-scaled studies on environmental determinants of parent-reported outside play of 5-7-year-old children. The study in chapter 4 particularly investigated the influence of parent-perceived physical and social environment on children's outside play. First, linear regression models investigated cross-sectional associations at ages 5 and 7. Second, linear mixed models were performed to evaluate whether the influence of correlates would become weaker or stronger as children age. Results showed social environmental determinants generally had a stronger relationship with outside play than perceived physical environmental determinants, at both five and seven years. In the social environment, habit strength towards parental promotion of outside play, the presence of parental rules regarding outside play, and having physically active siblings were stable correlates of outside play. These findings demonstrated that the social environment was a strong correlate of parent-reported outside play in 5 and 7-year-old children.

The study in chapter 5 focused on moderation mechanisms of parenting influences and social capital on the relationship between the physical environment and children's outside play. Measurements of the perceived physical environment were based on the Neighbourhood Environment Walkability Scale (4), and consisted of multiple-item constructs such as the accessibility of PA facilities. Self-reported parenting influences were multiple-item constructs describing, for example, parental pressure towards PA and active transport, or parental attitude towards regular PA. Results showed that parent-perceived accessibility to PA facilities, social capital in the neighborhood, and positive parental attitudes towards PA were associated with more parent-reported outside play. In contrast, concern regarding their child's PA and restriction of screen time were associated with fewer minutes of outside play. Although this study only found a limited number of significant interactions, it indicated that the perceived physical environment may have less influence if parents do not perceive responsibility regarding their child's PA levels. This may mean that these parents provide their child with more autonomy to play outside in spaces that they think are appropriate and safe.

Chapters 6, 7, 8 and 9 represent the fourth aim of this thesis: investigating the influence of the objective environment on children's' PA patterns using optimized methodologies, and to examine these patterns in the transition from childhood to adolescence.

Meteorological Environments as Determinants of PA

First, chapter 6 addresses a non-modifiable potential determinant of children's PA: daily weather elements. In this study, we examined the longitudinal influence of daily weather elements (e.g. rain, temperature) on children's PA patterns across the four seasons of one year, reflecting day-to-day variations within children in South-East Australia. Also, potential differences by age, gender, BMI, and type of day (weekdays versus weekend days) were investigated. Daily meteorological data were obtained from weather station registries that were closest to a child's residential location, and were matched with daily accelerometer measurements. Results showed that temperature and type of day (weekdays) were the strongest determinants of PA, followed by solar radiation and humidity. Associations did not differ by socio-demographic factors or BMI. In addition, a strong curvilinear relationship was found between temperature and MVPA, with optimum PA levels around 20-25 degrees Celsius. As this study showed substantially lower PA levels with higher temperatures, policy makers in Australia should consider providing measures to promote appropriate PA without risking sunburns or overheating on hotter days. In addition, this study discusses the necessity to account for weather elements in future studies, and demonstrates how this can be performed while using objective meteorological data and longitudinal designs.

Environmental Determinants of Afterschool PA

Chapters 7 and 8 both focus on objective determinants of the physical environment, in relation to objectively measured afterschool PA of 8-12-year-old children. Namely, chapter 7 addresses the quality and quantity of PA opportunities in the school environment, comprising the so-called playability index. Playability was studied by systematically auditing school-environments (defined by an 800-m buffer area) of 21 Dutch primary schools. Not only the location of children's residence, but also concurrent activities such as organized sports participation or daylight might influence whether children are physically active in their school environment. Therefore, we studied the relationship between playability of school environments and accelerometer-measured afterschool PA specifically for categories of children with various home-school distances, and within four afterschool time-segments. Children from schools with higher playability-scores spent more light PA and MVPA directly after school until 6 PM. This relationship was attenuated at later time-segments. In addition, we found that these results were strongest for children that lived within 400-m of their primary school. This relationship was no longer significant in children that lived more than 800-m from their school. These results demonstrate the importance of the quality and quantity of playgrounds in school environments. In addition, these results underline that relationships between attributes of the environment and PA can be elucidated by increasing specificity of time and place.

Chapter 8 describes a study on relationship between attributes of the physical environment and children's afterschool PA. Based on information from both Global Positioning Systems (GPS) and Geospatial Information Systems (GIS), this study was able to study specific behavioral contexts of the afterschool time-segment; leisure time, cycling and walking. This was done by excluding all data-points with GPS locations at the

participant's residence, school, sports grounds, afterschool childcare centers and shopping centers. In addition, this study focused on children's multi-place environment; conceptualized by the combined home-, school-, and daily transport environment between their home and school. Results showed that afterschool leisure time PA was associated with higher densities of greenspaces (i.e. lawns and shrubs), buildings and pedestrian paths, and smaller home-school distances. In addition, cycling was associated with greater home-school distances and higher densities of pedestrian areas and sports terrains, while fewer minutes of cycling were associated with higher densities of buildings, lawns, and pedestrian paths. More minutes of afterschool walking were associated with smaller home-school distances and higher densities of agriculture, shrubs, main roads, and pedestrian paths. Collectively, this study revealed attributes of the multi-place physical environment that relate to afterschool leisure time and transport-related PA.

PA Patterns in the Transition between Primary and Secondary School

Chapter 9 describes a longitudinal study on the development of PA patterns in the transition between primary and secondary school. The aim of this study was to add in-depth insights into where and in which time-segments of the day changes in children's PA patterns may occur. Based on information from GPS and GIS data, this study was able to specify multiple physical and behavioral contexts: participant's residence, school, sports grounds, shopping centers, and other places, and trips in active and passive transport. Multi-level linear mixed models were fitted adjusting for age, gender, meteorological circumstances, and the nested structure of measurement-days within children and children within schools. Results showed that total LPA and MVPA declined in the transition between primary and secondary school, especially after school and during weekends. The major drivers of decreasing PA from primary to secondary school were 1) increased sedentary time spent at the residence, 2) decreased LPA spent at sports grounds, and 3) decreased LPA and MVPA spent at other locations (e.g. time spent while visiting friends or time spent outside at places in the neighborhood but outside the house). Declines in afterschool PA were replaced with increased sedentary time at children's residence. Transport-related activity significantly increased during weekdays, and stronger increases were found for children with bigger increases in distance from the residence to their school.

What the Studies in this Thesis add to the Current Knowledge Base

Some overall conclusions can be drawn from this thesis. First, results from chapter 2 showed that increased MVPA was related to lower BMI standard deviation scores. Although several previous studies have suggested such a relationship (5, 6), this was the first study that showed differential effects by children's weight status at baseline. Second, chapter 3 discussed the relationship between PA enjoyment and PA behavior as being moderated by gender and impulsivity. Although age and gender are often suggested as key-moderators of this relationship, this was the first study to a-priori evaluate these interactions. Third, results from chapters 4 and 5 showed that especially perceived

accessibility to PA facilities and social environmental determinants (e.g. parenting influences, having active siblings) were important in explaining parent-reported outside play. These results underline the role of parents as gatekeepers in providing children the freedom to perform unstructured outside play. Fourth, chapters 6, 7, 8 and 9 reported on associations between the physical environment and children's PA, using methodological advances. As these methodological advances are still developing, these studies have addressed both empirical and methodological aims. Namely, results from chapter 6 discuss the influence of humidity, solar radiation, humidity, day length and rainfall on children's PA, and furthermore demonstrate the non-linear relationship between temperature and PA. The latter is in line with one previous study (7), and the study presented in chapter 6 was unique in investigating the influence of weather elements across all four seasons. The study presented in chapter 9 builds upon results from earlier studies showing declines of PA in the transition towards adolescence (8-14), and provides unique in-depth insight of where and in which time-segments changes in PA occur during the transition from primary to secondary school. Studies presented in chapters 7 and 8 focus on environmental determinants of afterschool PA. Previous studies highlight the importance of the afterschool period and its potential in increasing PA (15-17), but results from chapter 7 showed that the influence of playgrounds in the school environment is limited to the time-segment directly afterschool (until 6 PM), and for children living within 800-m from their school. This study provides an example of how important insights can be obtained from time- and spatial-filtering approaches. Chapter 8 focused the relationships between attributes of the physical (multi-place) environment and children's PA. Previous studies using accelerometers and GPS methodologies suggest that children are more active in greenspace environments such as parks (18-21), but results in chapter 8 add that children with higher densities of greenspace performed more afterschool leisure time PA compared to children with lower densities, irrespective of whether PA was actually performed at these greenspaces. These results may be an important step forward in acknowledging the importance of greenspace environments in objectively measured PA. Hence, urban planners and health promotors are encouraged to design natural experiments that strategically position greenspace in the shared publicly accessible home-school environment. In addition, future studies are encouraged to replicate these analyses in order to open opportunities for transcultural comparisons. In line with the previously described EnRG framework (3), this thesis both demonstrated that a direct pathway exists between environment and PA behaviour, and also that the pathway between (especially perceived) environment and PA is indeed moderated by parenting influences.

Methodological and Theoretical Considerations

Study Designs

In this thesis, two observational study designs were applied to investigate environmental determinants of PA; cross-sectional and longitudinal designs. The studies in chapters 3, 7 and 8 used cross-sectional designs. Although using these designs limits the ability to draw conclusions on causal inference, in this thesis they were useful in exploring alternative

methodologies and generating stronger hypotheses for future research. Namely, chapter 3 generated stronger hypotheses for individual-level motivational determinants of PA, using complex conceptual models involving moderation mechanisms. In chapter 7, an alternative methodology was explored by testing the strength of environmental determinants on afterschool PA using various filters of time and place. In chapter 8, this time-place methodology was further improved by investigating relationships between multi-place environmental determinants and additional context of PA during afterschool hours. The studies in chapters 4, 5, 6 and 9 used longitudinal designs, which provided valuable insights into how environmental determinants may influence PA over time. Determinants of PA, especially environmental determinants, are typically relatively stable over time. The value of longitudinal observations may be even further increased in case of *changes* in the environment as a determinant of PA behaviour. For example, as current evidence is emerging on promising features of PA-supporting environments such as greenspace and street connectivity (22, 23), the effectiveness of these environmental changes on children's PA over time can be investigated using natural experiments (24-26). By doing so, causal relationships between these environmental attributes and PA may be revealed.

Measurement of (context-specific) PA

Previous studies have traditionally focused on investigating aggregated levels of total PA, performed daily or across several days. For example, chapters 2, 3 and 6 investigated such associations with daily objectively measured PA. Numerous studies indicated the importance of objective measurements for daily PA, as self-reported or parent-reported questionnaires tend to significantly overestimate PA levels (27, 28). In addition, objective measurements such as accelerometers are independent of recall- or social desirability bias (29). However, accelerometers have their own challenges and limitations, such as varying thresholds for classification of intensity-levels (30), general incorrect measurement of cycling and static upper-body activities (31), varying definitions of non-wear time (32), and relative representativeness of measurements with respect to total habitual PA (33). Nevertheless, the use of accelerometers is still the recommended methodology to measure daily PA in free-living conditions.

In contrast to aggregated daily PA, accelerometers alone are unable to measure the context in which PA occurs (e.g. school from organized sports participation) (34-36). Contextual information is essential in understanding environment-behavior relationships, as environmental determinants, such as studied in chapters 7 and 8, have been shown to be context-specific (37). For example, accessibility to sports grounds may influence children's sports participation, but not their active transport to school. Therefore, previous studies have used self-reports or parent-reports to be able to focus on context-specific PA (38-40). In this thesis for example, chapters 4 and 5 investigated such associations with parent-reported child's outside play. Studies with clearly conceptualized assessments of the duration and frequency of specific PA-contexts and appropriate theoretical- and analytical frameworks, can still contribute to the evidence-base regarding determinants of specific PA-contexts.

Recently, researchers have applied novel methodologies to estimate the context by combining accelerometers with self-reported diaries (12, 41), developing algorithms recognizing the context in triaxial accelerometer patterns (42-44), time-segmented analyses of accelerometer data (11, 45, 46), or even combining accelerometers with GPS (18, 19, 47). An important first step towards more detailed context-specific PA analyses is to perform time-segmented analyses of accelerometer data based on children's school schedule, for example as presented in chapter 7. Namely, as children's exposure to the environment during school hours is largely limited by regulations, schedules and geographic location of their school, conceptually-matched relationships between environmental attributes and PA are likely to be found in the afterschool period or during weekends (10, 11, 45, 48). In this thesis, chapters 7 and 8 addressed environmental determinants of afterschool PA in children.

A second step towards context-specific PA lies in the combination of accelerometer and continuously logged GPS data. With the additional knowledge of the geographical location at which PA occurs, these data can be merged into Geographical Information Systems (GIS), which hold extensive data about characteristics of the built environment. In this way, the context of specific PA patterns (or sedentary behaviors) can be inferred from the contemporaneously-measured geographical location or travel speed (49-52). In this thesis, we have applied these recent methodological advances while investigating determinants of afterschool PA (chapter 8) and PA patterns in transition from primary to secondary school (chapter 9). These studies used the Personal Activity and Location Measurement System (PALMS), developed by the University of San Diego, to merge both measurements and to perform basic validation analyses (50). Several other studies developed their own methods for combining GPS and accelerometer data, which potentially hampers meaningful comparisons between studies (18, 19, 53-58). Although important steps have been taken to improve processing and analyses of the data (50-52, 59-61), and interpretation of the results (34, 49), GPS-methodologies are still developing. For example, future studies are encouraged to investigate the use of 1) accounting for measurement errors in the GPS location (59), 2) protocols for imputing missing GPS data points (61), and 3) handling accelerometer non-wear time. In addition, although analyses of both the behavioral- and spatial pattern add another layer of variability (and thus complexity) to the data, to date studies have based their wear time criteria on accelerometer-only criteria (33). When analysing combined GPS and accelerometer data, future studies may investigate the use of adapted criteria for daily wear time and the minimum number of days in which children should participate, to achieve sufficient intra-individual reliability.

Future studies are encouraged to replicate methodologies in chapters 7, 8 and 9 while investigating the time-segmented association with contextually matched environmental determinants. In this way, relationships between objectively measured environmental determinants and PA may be further unravelled. However, when analyzing smaller time-segments, researchers should acknowledge its contribution to daily PA and potential health benefits in the future (i.e. 'clinical relevance'). Potential contributions to daily PA

are closely related to the essential question of whether children either compensate their PA levels to maintain an innate total PA set point (i.e. activitystat hypothesis) (62), or that children do not compensate so that increases in one context are related to increases in another context (active synergy hypothesis) (63). Namely, increases of PA in small time-segments may be more likely to be compensated with increases in sedentary time during subsequent hours. Chapter 9 describes the development of PA patterns (segmented by time and location) throughout the whole day and across the transition from primary to secondary school, and some indications for potential compensation were found. To date, the available evidence regarding compensation of PA is however mixed (64). This greatly depends on the variable measured (activity energy expenditure versus PA) and the time-frame on which compensation is measured (day by day or across several months) (64). Potentially important innovations in investigating compensation-mechanisms in children may relate to the ability to measure posture with accelerometers (i.e. sitting, standing, lying) (44), and the integration of these accelerometers with 24-hour wear time protocols. In these designs, compositional data analyses may account for potential co-dependencies between sedentary behaviors, sleep and PA (65, 66).

Measurement of Environmental Exposure

Measuring exposure to environmental determinants of PA can be done by questionnaires (i.e. perceived environment) or by observation (i.e. objective environment). In this thesis, both types were used. Chapters 4 and 5 focused on the perceived environment. Previous studies that compared perceived with objective environmental determinants suggest that the two are interrelated, but different concepts (67-69). Namely, a person's exposure to the environment is influenced by personal factors and selective daily mobility (3, 70). In addition, children's definition of a 'neighborhood' or 'activity space' may be highly individual (34, 71, 72). Therefore, perceived environmental measures are still indispensable for understanding environment-behavior relationships. The study in chapter 7 conceptualized objective environmental determinants of afterschool PA by systematic environmental audits of playgrounds in the school environment. These audits were conducted using the SPACE checklist (73), based on the Neighborhood Environment Walkability Survey (74). This study applied GIS Euclidean and network buffer analyses to examine whether the distance from school to home would influence our relationship of interest. Whereas Euclidean buffers simply identify the environment within a circular distance, the network buffer accounts for barriers, such as rivers and highways. The study presented in chapter 7 showed no difference between network- and Euclidean buffers. In addition, as to date there is no consensus on what buffer size would be appropriate in Dutch primary school children, the study in chapter 7 investigated associations with various buffers sizes ranging from 400- to 1600 meters (69). As the SPACE checklist also included quality-indices (e.g. accessibility, availability of playing devices of playgrounds), this study was able to go beyond the opportunities of most objective measurements such as GIS. Future studies combining qualitative data (e.g. audits, interviews, or perceived environment questionnaires from both parents and children) may further enhance our understanding of which environmental attributes are PA-supportive in youth (75, 76).

Previous studies that investigated objective environmental determinants have traditionally focused on the residential neighborhood. However, people tend to spend considerable time outside their residential neighborhood (77, 78). Alternatively, environmental exposure may be defined by multiple locations (i.e. 'anchor points') and often travelled routes between these anchor points. GPS data may also allow researchers to analyze a participant's environmental exposure based on exact GPS locations. This means that environment-PA relationships are investigated within the same specific geographical location, measured within the same time frame (18-21, 56, 58, 79-82). With this so-called contemporaneous momentary design, the specificity of environmental exposure assessment may be improved (83). This design may be useful in epidemiological studies where geographical exposure (for a specified amount of time) can be defined when the GPS location is within a certain distance. In PA-studies however, the contemporaneous momentary design may be less useful as PA is a complex interplay between spontaneous and planned behavior; involving memory of location of PA facilities, time- and capacity constraints, social interactions, and compensation mechanisms. Also, contemporaneously momentary designs are vulnerable to selective daily mobility. This might occur when environments are deliberately visited for PA (e.g. sports grounds). In this way, it is not the environment that influences PA, but a participant's pre-conceived choice that biases directionality of the relationship between the determinant and PA (34, 49).

Consequently, modern GPS analyses present researchers with a trade-off between improved specificity of environmental exposure assessment versus the potential for causal inference (22, 34, 49). Future studies are therefore encouraged to incorporate frameworks from both health sciences (3) and transportation research (72), in order to make informed decisions about children's exposure environments (or activity spaces) based on distances between school and homes, and knowledge of potential other frequently visited anchor points. In addition, future studies may also exploit the potential of GPS logging for investigating social environmental determinants. As one study showed, it is possible to investigate locations of joint child-parent PA based on the nearness of the parent's and child's GPS locations (84); future studies may apply this by objectively measuring children's social interactions and locations where joint PA takes place.

Altogether, although objective measurements provide researchers with reliable estimates of specific attributes of the environment, the perceived environment and objective environment are considered to be conceptually different. Therefore, both can be complementary in PA research.

Selection Bias and Information Bias

Complete data-collection and prevention of selective loss to follow-up is of particular interest in PA studies, as accelerometer protocols require multiple days of measurement. In addition, most accelerometer data-reduction protocols forces researchers to exclude high amounts of data because of insufficient wear time. Missing data may be at random, or associated with participant characteristics. When missing values occur in a random pattern (i.e. unrelated to any outcome or determinant), they are expected to only reduce the power and precision of the associations. In this case, multiple imputation (MI) procedures are valid in preserving the power and precision of associations of interest.

On the other hand, when missing values occur in a non-random pattern, relationships may be significantly biased, and MI-procedures are not recommended. In this thesis, we observed that children's compliance to wear accelerometers was reduced with increased wear time. This was especially the case with the heavier and slightly more bothersome GPS loggers. Moreover, consistent with observations by Bürgi et al. (2015) and van Kann et al. (2016), participants sometimes mentioned that they deliberately removed the equipment while at a sports club, as they perceived the devices as uncomfortable (85, 86). This may potentially lead to selective loss of data, and therefore may bias associations at hand. Researchers may account for potential random loss of data due to decreased children's compliance by oversampling studies at baseline (61). Also, selection bias may occur in the recruitment of participants in these studies, as GPS loggers collect private or sensitive information. Therefore, these studies are encouraged to communicate transparent protocols regarding data analysis, reporting of results, anonymity, and storage of data. Technological advances in PA measurement are developing quickly. For example, with recent innovations in wrist-worn accelerometers (43), or smartphone applications (87) children may be more willing to wear equipment for multiple consecutive days, and to keep wearing the devices at sports clubs. However, prior to applying potentially less bothersome devices in population-based studies, assessing practical issues and validity of these fast-developing innovative devices is necessary (43).

Data Analyses

In this thesis, predominantly linear models were used, often accounting for multilevel clustering of seasonality/weather elements (chapters 3, 4, and 5) and children within schools/classrooms (chapters 8 and 9). However, as seen in the relationship between temperature and PA (chapter 6), relationships may not always be linear. Therefore, researchers are encouraged to investigate linearity and to apply non-linear models where appropriate. In addition, as described in chapters 8 and 9, minutes that children spent in specific contexts were often not normally distributed. Although log-transformations improve model-fit and help to meet the model assumptions, comparisons between independent variables and straightforward interpretation of the effect size is often difficult. Future researchers are encouraged to explore potential non-parametric testing in non-normally distributed PA data, in order to meet model assumptions and to preserve power and precision.

Ecological frameworks highlight interactive relationships between determinants and PA. This means that when interested in relationships between determinants and PA, third variables may play a role. First, a third variable may act as a confounder. Confounding variables bias the underlying relationship, as the variable is related to both the determinant and PA, while not being an intermediate factor in the causal pathway between the determinant and PA. Although it is important to adjust for potential confounders in multivariate models, residual confounding of unmeasured factors (or poorly measured variables due to misclassification) may have played a role in this thesis. Second, a third variable may act as a moderator or effect modifier. In this case, the relationships between the determinant and PA differs for the moderating variable. For example, in this thesis, we found some evidence that relationships between PA enjoyment and PA behavior differed by gender and impulsivity. In addition, we also found that children's responses to certain weather elements differed by type of the day (i.e. weekdays versus weekend days). Third, a third variable may act as a mediator. Mediating variables are related to both the determinant and PA, and are in between the causal pathway. Since in this thesis only observational studies were performed, we cannot speculate on potential causal pathways. Therefore, we did not speculate on potential mediating mechanisms in this thesis.

Consequently, researchers are encouraged to also consider non-linear relationships and non-normally distributions in predicting PA patterns, and to investigate possibilities of somewhat more dynamic approaches that test multiple mediating or moderating pathways such as agent-based models (88, 89) or structural equation models (90, 91). The increased demand on analyses investigating complex pathways explaining specific PA contexts often require subgroup analyses or time-segmented data. Moreover, as devices for PA measurement (e.g. accelerometers) still produce random errors and selective data loss is still an issue, this in turn may lead to power issues. Future studies should account for performing these refined analyses (e.g. afterschool time-segments) and measurement error in their power calculation.

Generalizability

A number of studies presented in this thesis used data from the KOALA Birth Cohort study (chapters 2, 3 and 5). This cohort study started in 2000 with the recruitment of healthy pregnant women from the general Dutch population, with a focus on the development of children's asthma and allergies, and growth and development. The samples included in our analyses consisted of relatively highly educated mothers (91% at least mid-high education) (92, 93), with relatively low percentages of non-Western ethnicities (94). In addition, chapters 8 and 9 used data from the PHASE-kids study. This study started in 2015 and recruited children in their last year of primary school, to investigate development of PA in the transitional phase to secondary school. Again, parents of participating children were relatively highly educated (44% of responding parents had at least a higher vocational diploma). This is comparable with rates of the Dutch general population of that age (95). Of the 30 primary schools that were invited to participate, 21 primary schools were included in the study. Also, approximately half of the recruited

participants participated in measurements. As no data were obtained from children and schools that refused to participate, it is not possible to investigate the magnitude of potential selection bias. In chapter 7, data was used from the Active Living study (96), which focused on the development of tailored school-centered PA interventions in deprived areas in the south of the Netherlands. The majority of included participants were of Dutch ethnicity (97). Chapter 4 used data from the Be Active Eat Right Study, of which 83% of the parents had mid-high education, and 91% of the children were of Dutch ethnic background (98).
In general, the Netherlands is a supportive environment for active transport. This is for example because of its highly connected streets, flatland, general nearness of children's homes to their schools, and absence of motorized transport infrastructures between home and school. In chapters 8 and 9, data was collected from a relatively urbanized area, whereas data from chapter 7 also included more rural areas. As children in rural areas often have bigger school-home distances, results between these studies may not be easily comparable. Therefore, future researchers may investigate whether children in rural areas have deviant PA patterns compared to children living in more urbanized areas. The study presented in chapter 6 was based on data from the PHASE study, which was carried out in Melbourne, Australia. The meteorological circumstances (especially high temperatures) experienced in these regions may be not generalizable to North-European countries, as temperatures tend to be lower especially in spring and summer (99, 100).

Collectively, the majority of results presented in this thesis were collected from children from relatively highly educated Dutch parents, and in (physical and social) environments supportive of active transport. Therefore, results presented in this thesis may not be generalizable to different samples with other environments, generally lower educational levels, or with a more diverse ethnic makeup. Although our results may not easily be generalized, the methodology used in especially chapters 7, 8 and 9 may provide researchers with examples on how to investigate time-specific and location-specific associations between environmental determinants and PA, also in other samples and countries.

Effect Sizes

In the majority of the studies presented in this thesis, effect sizes may be considered small, and highly dependent on the context. This is in line with comparable studies focusing on PA (102). For example, chapter 2 describes a study that showed that an increment of 6.5 minutes of MVPA over at least three days was associated with 0.03 lower BMI scores. Another example is from chapter 7, which describes a study on environmental determinants of afterschool PA in the home-school environment. Results showed an influence of specific attributes of the built environment, but these were highly context-dependent (i.e. afterschool leisure time PA, cycling and walking). These small effect sizes may for example be influenced by measurement errors in the assessment of the environment using GPS and GIS methodologies. Namely, GPS loggers in general tend to make errors in determining locations; whereas the specific device used in chapters 8 and 9 performs somewhat better in both static and free-living conditions (59, 101). Although

researchers tend to account for these errors in the buffer size, misclassifications still cannot be avoided. Consequently, although the direction and strength of investigated determinants may be comparable between studies, specific effect sizes may be difficult to compare and generalize to other contexts. This makes it challenging to evaluate the impact of attributes of the physical environment on PA behavior in children, and ultimately to assess the impact of PA on children's health.

Recommendations for practice

The following is recommended for health promotors and policy makers:

- Promotion of regular PA and limiting sedentary time should remain a primary target in the prevention of overweight and obesity, especially in heavier boys and girls (chapter 2), next to other known behavioral determinants of weight gain such as dietary behavior and sleep. Health promotors are also encouraged to emphasize the emerging short-term benefits of increased PA on children's cognitive, social and emotional well-being.
- Schools and playgrounds in the school environment play an important role in the promotion of PA (chapters 7 and 9) (47, 85, 86, 102, 103). As schools are evaluated primarily on children's cognitive performance, health promotion is sometimes perceived as a secondary objective. However, recent findings suggesting associations between PA and improved cognitive performance, may help to integrate PA into daily school curricula (104, 105). In addition, high-quality physical education may enhance children's PA, well-being and competency, and related physical literacy (106-108). Previously developed school-based PA interventions indicate the potential of multi-setting and bottom-up approaches in improving children's PA levels (e.g. schools, communities, and parents), while acknowledging the local school-context (96, 109-111).
- Individual-level determinants of PA in children are part of a multidimensional construct involving, for example, enjoyment, quality of motivation, fundamental movement skills, general self-concept and self-efficacy (chapter 3) (106, 107, 112). Interventions targeting individual-level determinants should take into account the interactive contribution of each of these factors, and that these may depend on the context of PA (e.g. organized sports participation versus physical education).
- Improving young children's outside play require interventions involving their parents, as they act as gatekeepers in providing their child with opportunities for outside play (chapters 4 and 5). This is in line with previous research focusing on children's active transport and free play (76, 113-115). These interventions may, for example, involve awareness of accessibility to PA facilities (chapter 5) or safety issues (116).
- Environmental determinants of PA are highly context-specific (chapters 7, 8 and 9). Critical consideration of time- and place-specificity, as well as the influence of weather elements is therefore recommended (chapters 6 and 7). Evidence on the influence of specific environmental determinants on PA is currently still

considered marginal (22, 23, 111, 117, 118), and dependent on higher-order conditions (119). Health promotors are recommended to target specific PA contexts from multiple contexts (e.g. school and home environment), and collaborate with various stakeholders to ensure local support (e.g. schools, parents, local community). However, as evidence on the potential positive influence of greenspace environments, cycling paths and pedestrian paths is emerging, health promotion researchers are advised to implement small-scale natural experiments in collaboration with local stakeholders, and evaluate the influence of such environmental attributes on children's PA and well-being.

- In the transition from primary to secondary school, notable declines in PA are being reported (chapter 9) (12, 41, 45, 120, 121). Future studies are encouraged to investigate PA patterns in this transition, and as considerable changes occur in both the school environment and social environment, future interventions are recommended to target both environments.

Recommendations for future research

This thesis recommends the following for researchers and future study designs:

- Researchers are encouraged to continue their efforts into investigating environmental determinants of PA. As the perceived and objective environment are considered to be conceptually different, these can be complementary in PA research (34). Of special interest is the influence of greenspace areas and street connectivity for bicycling and walking. Future studies should increase the evidence-base regarding these attributes of the environment into longitudinal designs, possibly involving natural experiments or transcultural comparisons.
- Future studies should continue to unravel complex longitudinal relationships between PA and potential long term health benefits such as body composition and bone strength (122). Studies are also encouraged to investigate potential shorter-term benefits of regular PA on cognitive, emotional, and social well-being of children.
- Results from this thesis showed that the influence of environmental determinants on PA depend on the context. Future studies may replicate the analyses presented in this thesis; for example by investigating higher-order moderators of environmental determinants of afterschool PA, or active transport to school. Furthermore, researchers are recommended to account for the location and time-segment in which environmental determinants influence PA. This thesis also showed that adjusting for meteorological elements is essential in understanding day-to-day PA patterns in children. Finally, additional studies are warranted that investigate the PA patterns in important transitional phases of childhood development (e.g. adiposity rebound, pre-school to elementary school, or childhood to adolescence).
- In contrast to focusing on more specific contexts within PA behavior, future studies may also focus on PA in the larger context of sleep and sedentary behaviors (66). When using validated leg-worn accelerometers (123), so-called

compositional data analyses may reveal interesting co-dependencies between these behaviors that in turn may have different consequences on children's health (66).

- Complex conceptual models involving mediation and moderation provides researchers with valuable deeper insight into how determinants influence PA. In addition to the relatively isolated approach of moderation as described in this thesis, more flexible approaches such as structural equation modelling or agent-based modelling have the potential of simultaneously investigating multiple moderation or mediation mechanisms (88, 91). We recommend embedding these analyses in well-conceived theoretical frameworks.
- Researchers should take into account that combined accelerometer and GPS methodologies may lead to decreased compliance in wear time, especially with repeated measurements. Also, due to potential concerns about privacy and data-storage, selection bias may occur. Therefore, future studies are encouraged to develop and communicate clear protocols regarding data-storage and analyses, as well as consider oversampling the population of interest.
- The increased acknowledgement of the importance of regular PA has led to recent advances in consumer-level PA monitors. These monitors tend to be more user-friendly, relatively cheap, allow users to upload and review their data in online applications, and can be worn on the hip or wrist (124). As some consumer-level monitors tend to perform well in capturing daily accumulated steps compared to more advanced research-level monitors, this may offer exciting possibilities to analyze participant's PA in real-time (124-126). Although these innovations may be inspiring, there are still numerous additional challenges to overcome before consumer-level monitors can be used for research purposes; for example, these include improving concurrent-validity of especially MVPA classifications, data ownership and privacy, blinding participants for individual feedback in observational studies, and identification of cycling and motorized transport.
- Driven by fast developing technological innovations, researchers are strongly encouraged to continue their efforts into the feasibility, reliability and validity of new research-level monitors to quantify PA, sleep, and sedentary behaviors. Of special interest are smaller, more comfortable monitors, with enhanced battery-life and data-storage capacities. While combining data from multiple sensors, these devices may be able to recognize daily composition (i.e. sleep, sedentary behaviors, and PA) and specific PA contexts (e.g. bicycling, sports participation). As these new devices may cause less burden for participants, study designs with considerably longer monitoring periods may be feasible. With these longer monitoring periods, researchers may be able to, for example, investigate compensation-mechanisms across longer time periods (64).

References

1. Fredriks AM, van Buuren S, Wit JM, Verloove-Vanhorick S. Body index measurements in 1996–7 compared with 1980. Archives of Disease in Childhood. 2000;82(2):107-12.
2. Motl RW, Dishman RK, Saunders R, Dowda M, Felton G, Pate RR. Measuring enjoyment of physical activity in adolescent girls. American Journal of Preventive Medicine. 2001;21(2):110-7.
3. Kremers SP, De Bruijn GJ, Visscher TL, Van Mechelen W, De Vries NK, Brug J. Environmental influences on energy balance-related behaviors: a dual-process view. International Journal of Behavioral Nutrition and Physical Activity. 2006;3(1):9.
4. Rosenberg D, Ding D, Sallis JF, Kerr J, Norman GJ, Durant N, et al. Neighborhood Environment Walkability Scale for Youth (NEWS-Y): reliability and relationship with physical activity. Preventive Medicine. 2009;49(2);213-8.
5. Jago R, Baranowski T, Baranowski JC, Thompson D, Greaves K. BMI from 3-6 y of age is predicted by TV viewing and physical activity, not diet. Internation Journal of Obesity. 2005;29(6):557.
6. Moore LL, Gao D, Bradlee ML, Cupples LA, Sundarajan-Ramamurti A, Proctor MH, et al. Does early physical activity predict body fat change throughout childhood? Preventive Medicine. 2003;37(1):10-7.
7. Lewis L, Maher C, Belanger K, Tremblay M, Chaput J, Olds T. At the mercy of the gods: associations between weather, physical activity and sedentary time in children. Pediatric Exercise Science. 2016;28(1):152-63.
8. Telama R. Tracking of physical activity from childhood to adulthood: A Review. Obesity Facts. 2009;2(3):187-95.
9. Nader PR, Bradley RH, Houts RM, McRitchie SL, O'Brien M. Moderate-to-vigorous physical activity from ages 9 to 15 years. Journal of the American Medical Association. 2008;300(3):295-305.
10. Brooke HL, Atkin AJ, Corder K, Ekelund U, van Sluijs EM. Changes in time-segment specific physical activity between ages 10 and 14 years: A longitudinal observational study. Journal of Science and Medicine in Sport. 2014;19(1):29-34.
11. Harding SK, Page AS, Falconer C, Cooper AR. Longitudinal changes in sedentary time and physical activity during adolescence. International Journal of Behavioral Nutrition and Physical Activity. 2015;12(1):44.
12. Marks J, Barnett LM, Strugnell C, Allender S. Changing from primary to secondary school highlights opportunities for school environment interventions aiming to increase physical activity and reduce sedentary behaviour: a longitudinal cohort study. International Journal of Behavioral Nutrition and Physical Activity. 2015;12(1):59.
13. Kristensen PL, Møller N, Korsholm L, Wedderkopp N, Andersen LB, Froberg K. Tracking of objectively measured physical activity from childhood to

adolescence: the European youth heart study. Scandinavian Journal of Medicine & Science in Sports. 2008;18(2):171-8.
14. Corder K, Sharp SJ, Atkin AJ, Griffin SJ, Jones AP, Ekelund U, et al. Change in objectively measured physical activity during the transition to adolescence. British Journal of Sports Medicine. 2015(49):730-6.
15. Timperio A, Giles-Corti B, Crawford D, Andrianopoulos N, Ball K, Salmon J, et al. Features of public open spaces and physical activity among children: Findings from the CLAN study. Preventive Medicine. 2008;47(5):514-8.
16. Scott MM, Evenson KR, Cohen DA, Cox CE. Comparing perceived and objectively measured access to recreational facilities as predictors of physical activity in adolescent girls. Journal of Urban Health. 2007;84(3):346.
17. Dale D, Corbin CB, Dale KS. Restricting opportunities to be active during school time: do children compensate by increasing physical activity levels after school? Research Quarterly for Exercise and Sport. 2000;71.
18. Almanza E, Jerrett M, Dunton G, Seto E, Pentz MA. A study of community design, greenness, and physical activity in children using satellite, GPS and accelerometer data. Health & Place. 2012;18(1):46-54.
19. Wheeler BW, Cooper AR, Page AS, Jago R. Greenspace and children's physical activity: a GPS/GIS analysis of the PEACH project. Preventive Medicine. 2010;51(2):148-52.
20. Rodríguez DA, Cho GH, Evenson KR, Conway TL, Cohen D, Ghosh-Dastidar B, et al. Out and about: association of the built environment with physical activity behaviors of adolescent females. Health & Place. 2012;18(1):55-62.
21. Troped PJ, Wilson JS, Matthews CE, Cromley EK, Melly SJ. The built environment and location-based physical activity. American Journal of Preventive Medicine. 2010;38(4):429-38.
22. McCrorie PR, Fenton C, Ellaway A. Combining GPS, GIS, and accelerometry to explore the physical activity and environment relationship in children and young people - a review. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1):93.
23. McGrath LJ, Hopkins WG, Hinckson EA. Associations of objectively measured built-environment attributes with youth moderate–vigorous physical activity: a systematic review and meta-analysis. Sports Medicine. 2015;45(6):841-65.
24. Andersen HB, Christiansen LB, Klinker CD, Ersbøll AK, Troelsen J, Kerr J, et al. Increases in use and activity due to urban renewal: effect of a natural experiment. American Journal of Preventive Medicine. 2017;53(3):81-7.
25. Veitch J, Salmon J, Carver A, Timperio A, Crawford D, Fletcher E, et al. A natural experiment to examine the impact of park renewal on park-use and park-based physical activity in a disadvantaged neighbourhood: the REVAMP study methods. BMC Public health. 2014;14(1):600.
26. Craig P, Cooper C, Gunnell D, Haw S, Lawson K, Macintyre S, et al. Using natural experiments to evaluate population health interventions: new

Medical Research Council guidance. Journal of Epidemiology and Community Health. 2012;66(12):1182-6.
27. Chinapaw MJM, Mokkink LB, van Poppel MNM, van Mechelen W, Terwee CB. Physical activity questionnaires for youth: a systematic review of measurement properties. Sports Medicine. 2010;40(7):539-63.
28. Helmerhorst HHJ, Brage S, Warren J, Besson H, Ekelund U. A systematic review of reliability and objective criterion-related validity of physical activity questionnaires. International Journal of Behavioral Nutrition and Physical Activity. 2012;9(1):103.
29. Corder K, van Sluijs EM, Goodyer I, Ridgway CL, Steele RM, Bamber D, et al. Physical activity awareness of British adolescents. Archives of Pediatrics & Adolescent Medicine. 2011;165(7):603-9.
30. Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. Medicine & Science in Sports & Exercise. 2011;43(7):1360-8.
31. Rowlands AV. Accelerometer assessment of physical activity in children: an update. Pediatric Exercise Science. 2007;19(3):252-66.
32. Evenson KR, Terry JW. Assessment of differing definitions of accelerometer nonwear time. Research Quarterly for Exercise and Sport. 2009;80(2):355-62.
33. Trost SG, Pate RR, Freedson PS, Sallis JF, Taylor WC. Using objective physical activity measures with youth: how many days of monitoring are needed? Medicine & Science in Sports & Exercise. 2000;32(2):426.
34. Perchoux C, Chaix B, Cummins S, Kestens Y. Conceptualization and measurement of environmental exposure in epidemiology: Accounting for activity space related to daily mobility. Health & Place. 2013;21:86-93.
35. Barisic A, Leatherdale ST. Importance of frequency, intensity, time and type (FITT) in physical activity assessment for epidemiological research. Canadian Journal of Public Health. 2011;102(3):174.
36. Ridgers ND, Timperio A, Cerin E, Salmon J. Within-and between-day associations between children's sitting and physical activity time. BMC Public health. 2015;15(1):950.
37. Giles-Corti B, Timperio A, Bull F, Pikora T. Understanding physical activity environmental correlates: increased specificity for ecological models. Exercise and Sport Sciences Reviews. 2005;33(4):175-81.
38. Aarts MJ, Vries SI, Oers HA, Schuit AJ. Outdoor play among children in relation to neighborhood characteristics: a cross-sectional neighborhood observation study. International Journal of Behavioral Nutrition and Physical Activity. 2012;9(1):98.
39. Prins RG, van Empelen P, Te Velde SJ, Timperio A, van Lenthe FJ, Tak NI, et al. Availability of sports facilities as moderator of the intention–sports participation relationship among adolescents. Health Education Research 2010;25(3):489-97.

40. Grow HM, Saelens BE, Kerr J, Durant NH, Norman GJ, Sallis JF. Where are youth active? Roles of proximity, active transport, and built environment. Medicine & Science in Sports & Exercise. 2008;40(12):2071-9.
41. Cooper AR, Jago R, Southward EF, Page AS. Active travel and physical activity across the school transition: the PEACH Project. Medicine & Science in Sports & Exercise. 2012;44(10):1890-7.
42. De Vries SI, Engels M, Garre FG. Identification of children's activity type with accelerometer-based neural networks. Medicine & Science in Sports & Exercise. 2011;43(10):1994-9.
43. Trost SG, Zheng Y, Wong W-K. Machine learning for activity recognition: hip versus wrist data. Physiological Measurement. 2014;35(11):2183.
44. Steeves JA, Bowles HR, McClain JJ, Dodd KW, Brychta RJ, Wang J, et al. Ability of thigh-worn ActiGraph and activPAL monitors to classify posture and motion. Medicine & Science in Sports & Exercise. 2015;47(5):952-9.
45. De Baere S, Lefevre J, De Martelaer K, Philippaerts R, Seghers J. Temporal patterns of physical activity and sedentary behavior in 10–14 year-old children on weekdays. BMC Public Health. 2015;15(1):791.
46. Knuth AG, Hallal PC. Temporal trends in physical activity: a systematic review. Journal of Physical Activity and Health. 2009;6(5):548-59.
47. Klinker C, Schipperijn J, Kerr J, Ersbøll A, Troelsen J. Context-Specific Outdoor Time and Physical Activity among School-Children Across Gender and Age: Using Accelerometers and GPS to Advance Methods. Frontiers in Public Health. 2014;2(20).
48. Arundell L, Ridgers ND, Veitch J, Salmon J, Hinkley T, Timperio A. 5-year changes in afterschool physical activity and sedentary behavior. American Journal of Preventive Medicine. 2013;44(6):605-11.
49. Chaix B, Meline J, Duncan S, Merrien C, Karusisi N, Perchoux C, et al. GPS tracking in neighborhood and health studies: a step forward for environmental exposure assessment, a step backward for causal inference? Health & Place. 2013;21:46-51.
50. Jankowska MM, Schipperijn J, Kerr J. A framework for using GPS data in physical activity and sedentary behavior studies. Exercise and Sport Sciences Reviews. 2015;43(1):48.
51. Carlson JA, Jankowska MM, Meseck K, Godbole S, Natarajan L, Raab F, et al. Validity of PALMS GPS scoring of active and passive travel compared with SenseCam. Medicine & Science in Sports & Exercise. 2015;47(3):662-7.
52. Kerr J, Norman G, Godbole S, Raab F, Demchak B, Patrick K. Validating GPS data with the PALMS system to detect different active transportation modes. Medicine & Science in Sports & Exercise. 2012;44:647.
53. Dessing D, de Vries SI, Graham JM, Pierik FH. Active transport between home and school assessed with GPS: a cross-sectional study among Dutch elementary school children. BMC Public Health. 2014;14(1):227.
54. Dessing D, Pierik FH, Sterkenburg RP, van Dommelen P, Maas J, de Vries SI. Schoolyard physical activity of 6–11 year old children assessed by GPS and

accelerometry. International Journal of Behavioral Nutrition and Physical Activity. 2013;10(1):97.
55. Bürgi R, Tomatis L, Murer K, de Bruin ED. Spatial physical activity patterns among primary school children living in neighbourhoods of varying socioeconomic status: a cross-sectional study using accelerometry and Global Positioning System. BMC Public Health. 2016;16(1):282.
56. Jones AP, Coombes EG, Griffin SJ, van Sluijs EM. Environmental supportiveness for physical activity in English schoolchildren: a study using Global Positioning Systems. International Journal of Behavioral Nutrition and Physical Activity. 2009;6(1):42.
57. Cooper AR, Page AS, Wheeler BW, Hillsdon M, Griew P, Jago R. Patterns of GPS measured time outdoors after school and objective physical activity in English children: the PEACH project. International Journal of Behavioral Nutrition and Physical Activity. 2010;7(1):31.
58. Quigg R, Gray A, Reeder AI, Holt A, Waters DL. Using accelerometers and GPS units to identify the proportion of daily physical activity located in parks with playgrounds in New Zealand children. Preventive Medicine. 2010;50(5):235-40.
59. Schipperijn J, Kerr J, Duncan S, Madsen T, Klinker CD, Troelsen J. Dynamic accuracy of GPS receivers for use in health research: a novel method to assess GPS accuracy in real-world settings. Frontiers in Public Health. 2014;2:21.
60. Kerr J, Duncan S, Schipperjin J. Using global positioning systems in health research: a practical approach to data collection and processing. American Journal of Preventive Medicine. 2011;41(5):532-40.
61. Klinker CD, Schipperijn J, Toftager M, Kerr J, Troelsen J. When cities move children: Development of a new methodology to assess context-specific physical activity behaviour among children and adolescents using accelerometers and GPS. Health & Place. 2015;31:90-9.
62. Rowland TW. The biological basis of physical activity. Medicine and science in sports and exercise. 1998;30(3):392-9.
63. Goodman A, Mackett RL, Paskins J. Activity compensation and activity synergy in British 8–13year olds. Preventive Medicine. 2011;53(4):293-8.
64. Gomersall SR, Rowlands AV, English C, Maher C, Olds TS. The ActivityStat Hypothesis. Sports medicine. 2013;43(2):135-49.
65. Carson V, Tremblay MS, Chaput J-P, Chastin SF. Associations between sleep duration, sedentary time, physical activity, and health indicators among Canadian children and youth using compositional analyses. Applied Physiology, Nutrition, and Metabolism. 2016;41(6):294-302.
66. Chastin SF, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined effects of time spent in physical activity, sedentary behaviors and sleep on obesity and cardio-metabolic health markers: a novel compositional data analysis approach. PLoS One. 2015;10(10).

67. Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth: a review. American Journal of Preventive Medicine. 2011;41(4):442-55.
68. Pikora T, Giles-Corti B, Bull F, Jamrozik K, Donovan R. Developing a framework for assessment of the environmental determinants of walking and cycling. Social Science & Medicine. 2003;56(8):1693-703.
69. Brownson RC, Hoehner CM, Day K, Forsyth A, Sallis JF. Measuring the built environment for physical activity: state of the science. American Journal of Preventive Medicine. 2009;36(4):99-123.
70. Spence JC, Lee RE. Toward a comprehensive model of physical activity. Psychology of Sports and Exercise. 2003;4(1):7-24.
71. Hume C, Salmon J, Ball K. Children's perceptions of their home and neighborhood environments, and their association with objectively measured physical activity: a qualitative and quantitative study. Health Education Research 2004;20(1):1-13.
72. Hägerstrand T. Time-geography: focus on the corporeality of man, society and environment: the science and praxis of complexity. 1985:193-216.
73. De Vries SI, Hopman-Rock M, Bakker I, Hirasing RA, Van Mechelen W. Built environmental correlates of walking and cycling in Dutch urban children: results from the SPACE study. International Journal of Environmental Research and Public Health. 2010;7(5):2309-24.
74. Saelens B, Sallis J, Black J, Chen D. Neighborhood-based differences in physical activity: an environment scale evaluation. American Journal of Public Health. 2003;93(9):1552-8.
75. Veitch J, Bagley S, Ball K, Salmon J. Where do children usually play? A qualitative study of parents' perceptions of influences on children's active free-play. Health & Place. 2006;12(4):383-93.
76. Veitch J, Salmon J, Ball K. Children's active free play in local neighborhoods: a behavioral mapping study. Health Education Research 2008;23(5):870-9.
77. Cummins S. Commentary: investigating neighbourhood effects on health—avoiding the 'local trap'. International Journal of Epidemiology. 2007;36(2):355-7.
78. Rainham D, McDowell I, Krewski D, Sawada M. Conceptualizing the healthscape: contributions of time geography, location technologies and spatial ecology to place and health research. Social Science & Medicine. 2010;70(5):668-76.
79. Maddison R, Jiang Y, Hoorn SV, Exeter D, Mhurchu CN, Dorey E. Describing patterns of physical activity in adolescents using global positioning systems and accelerometry. Pediatric Exercise Science. 2010;22(3):392-407.
80. Oreskovic NM, Blossom J, Field AE, Chiang SR, Winickoff JP, Kleinman RE. Combining global positioning system and accelerometer data to determine the locations of physical activity in children. Geospatial Health. 2012;6(2):263-72.

81. Rainham DG, Bates CJ, Blanchard CM, Dummer TJ, Kirk SF, Shearer CL. Spatial classification of youth physical activity patterns. American Journal of Preventive Medicine. 2012;42(5):87-96.
82. Coombes E, van Sluijs E, Jones A. Is environmental setting associated with the intensity and duration of children's physical activity? Findings from the SPEEDY GPS study. Health & Place. 2013;20:62-5.
83. Krenn PJ, Titze S, Oja P, Jones A, Ogilvie D. Use of global positioning systems to study physical activity and the environment: a systematic review. American Journal of Preventive Medicine. 2011;41(5):508-15.
84. Dunton GF, Liao Y, Almanza E, Jerrett M, Spruijt-Metz D, Pentz MA. Locations of joint physical activity in parent–child pairs based on accelerometer and GPS monitoring. Annals of Behavioral Medicine. 2013;45(1):162-72.
85. Van Kann D, Kremers S, de Vries N, de Vries S, Jansen M. The effect of a school-centered multicomponent intervention on daily physical activity and sedentary behavior in primary school children: the active living study. Preventive Medicine. 2016;89:64-9.
86. Bürgi R, Tomatis L, Murer K, de Bruin ED. Localization of physical activity in primary school children using accelerometry and global positioning system. PLoS One. 2015;10(11).
87. Bort-Roig J, Gilson ND, Puig-Ribera A, Contreras RS, Trost SG. Measuring and influencing physical activity with smartphone technology: a systematic review. Sports Medicine. 2014;44(5):671-86.
88. Yang Y, Roux AVD, Auchincloss AH, Rodriguez DA, Brown DG. A spatial agent-based model for the simulation of adults' daily walking within a city. American Journal of Preventive Medicine. 2011;40(3):353-61.
89. Macal CM, North MJ. Tutorial on agent-based modelling and simulation. Journal of Simulation. 2010;4(3):151-62.
90. Bois JE, Sarrazin PG, Brustad RJ, Trouilloud DO, Cury F. Elementary schoolchildren's perceived competence and physical activity involvement: the influence of parents' role modelling behaviours and perceptions of their child's competence. Psychology of Sports and Exercise. 2005;6(4):381-97.
91. Dishman RK, Motl RW, Saunders R, Felton G, Ward DS, Dowda M, et al. Self-efficacy partially mediates the effect of a school-based physical-activity intervention among adolescent girls. PLoS Medicine. 2004;38(5):628-36.
92. Remmers T, Van Kann D, Gubbels J, Schmidt S, de Vries S, Ettema D, et al. Moderators of the longitudinal relationship between the perceived physical environment and outside play in children: the KOALA birth cohort study. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1):150.
93. Kummeling I, Thijs C, Penders J, Snijders BE, Stelma F, Reimerink J, et al. Etiology of atopy in infancy: the KOALA birth cohort study. Pediatric Allergy and Immunology. 2005;16(8):679-84.
94. Gubbels JS, Kremers S, Stafleu A, de Vries SI, Goldbohm RA, Dagnelie PC, et al. Association between parenting practices and children’s dietary intake,

activity behavior and development of body mass index: the KOALA Birth Cohort Study. International Journal of Behavioral Nutrition and Physical Activity. 2011;8(1):18.

95. CBS Statline: Statistics Netherlands. Education level in the Netherlands the Hague 2017 Available from:https://www.volksgezondheidenzorg.info/onderwerp/sociaaleconomische-status/cijfers-context/opleiding - node-opleidingsniveau-naar-leeftijd.
96. Van Kann DH, Jansen M, De Vries SI, De Vries N, Kremers SP. Active Living: development and quasi-experimental evaluation of a school-centered physical activity intervention for primary school children. BMC Public health. 2015;15(1):1315.
97. Remmers T, Van Kann D, Thijs C, de Vries S, Kremers S. Playability of school-environments and after-school physical activity among 8–11 year-old children: specificity of time and place. International Journal of Behavioral Nutrition and Physical Activity. 2016;13(1):82.
98. Remmers T, Broeren SM, Renders CM, Hirasing RA, van Grieken A, Raat H. A longitudinal study of children's outside play using family environment and perceived physical environment as predictors. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1):76.
99. Remmers T, Kremers S, Ettema D, de Vries S, Thijs C. Unravelling the Context: Investigating the Development of Context Specific Physical Activity Patterns in Transition from Primary to Secondary School using Accelerometers, GPS, and GIS. Submitted for Publication.
100. Remmers T, Thijs C, Ettema D, de Vries S, Slingerland M, Kremers S. Critical Hours and Important Environments: After-School Physical Activity and the Built Environment using GPS, GIS and Accelerometers in 10-12-year-old Children. Submitted for Publication.
101. Duncan S, Stewart TI, Oliver M, Mavoa S, MacRae D, Badland HM, et al. Portable Global Positioning System Receivers: Static Validity and Environmental Conditions. American Journal of Preventive Medicine. 2013;44(2):19-29.
102. Strong WB, Malina RM, Blimkie CJ, Daniels SR, Dishman RK, Gutin B, et al. Evidence based physical activity for school-age youth. Journal of Pediatrics. 2005;146(6):732-7.
103. Ridgers ND, Salmon J, Parrish AM, Stanley RM, Okely AD. Physical activity during school recess: a systematic review. American Journal of Preventive Medicine. 2012;43(3):320-8.
104. Singh A, Uijtdewilligen L, Twisk JW, Van Mechelen W, Chinapaw MJ. Physical activity and performance at school: a systematic review of the literature including a methodological quality assessment. Archives of Pediatrics & Adolescent Medicine. 2012;166(1):49-55.
105. Donnelly JE, Hillman CH, Castelli D, Etnier JL, Lee S, Tomporowski P, et al. Physical activity, fitness, cognitive function, and academic achievement in

children: a systematic review. Medicine & Science in Sports & Exercise. 2016;48(6):1197-222.
106. Giblin S, Collins D, Button C. Physical literacy: importance, assessment and future directions. Sports Medicine. 2014;44(9):1177-84.
107. Whitehead M. The concept of physical literacy. European Journal of Physical Education. 2001;6(2):127-38.
108. Harwood CG, Keegan RJ, Smith JM, Raine AS. A systematic review of the intrapersonal correlates of motivational climate perceptions in sport and physical activity. Psychology of Sports and Exercise. 2015;18:9-25.
109. Gubbels JS, Kremers SP, Van Kann DH, Stafleu A, Candel MJ, Dagnelie PC, et al. Interaction between physical environment, social environment, and child characteristics in determining physical activity at child care. Health Psychology. 2011;30(1):84.
110. Willeboordse M, Jansen M, van den Heijkant S, Simons A, Winkens B, de Groot R, et al. The Healthy Primary School of the Future: study protocol of a quasi-experimental study. BMC Public Health. 2016;16(1):639.
111. Van Sluijs EM, McMinn AM, Griffin SJ. Effectiveness of interventions to promote physical activity in children and adolescents: systematic review of controlled trials. British Medical Journal. 2007;335(7622):703.
112. Babic MJ, Morgan PJ, Plotnikoff RC, Lonsdale C, White RL, Lubans DR. Physical activity and physical self-concept in youth: systematic review and meta-analysis. Sports Medicine. 2014;44(11):1589-601.
113. Van Kann D, Kremers S, de Vries S, de Vries N, Jansen M. Parental active transportation routines (PATRns) as a moderator of the association between neighborhood characteristics and parental influences and active school transportation. Environment and Behavior. 2016;48(7):946-65.
114. Carver A, Timperio A, Crawford D. Parental chauffeurs: what drives their transport choice? Journal of Transport Geography. 2013;26:72-7.
115. Carver A, Timperio A, Hesketh K, Crawford D. Are safety-related features of the road environment associated with smaller declines in physical activity among youth? Journal of Urban Health. 2010;87(1):29-43.
116. Carver A, Timperio A, Crawford D. Playing it safe: The influence of neighbourhood safety on children's physical activity - a review. Health & Place. 2008;14(2):217-27.
117. Ding D, Gebel K. Built environment, physical activity, and obesity: what have we learned from reviewing the literature? Health & Place. 2012;18(1):100-5.
118. Lachowycz K, Jones A. Greenspace and obesity: a systematic review of the evidence. Obesity Reviews. 2011;12(5):183-9.
119. Gubbels J, Van Kann D, de Vries N, Thijs C, Kremers S. The next step in health behavior research: the need for ecological moderation analyses - an application to diet and physical activity at childcare. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1):52.

120. Jago R, Page AS, Cooper AR. Friends and physical activity during the transition from primary to secondary school. Medicine & Science in Sports & Exercise. 2012;44(1):111-7.
121. De Meester F, Van Dyck D, De Bourdeaudhuij I, Deforche B, Cardon G. Changes in physical activity during the transition from primary to secondary school in Belgian children: what is the role of the school environment? BMC Public Health. 2014(14):261.
122. Richmond RC, Smith GD, Ness AR, den Hoed M, McMahon G, Timpson NJ. Assessing causality in the association between child adiposity and physical activity levels: a Mendelian randomization analysis. PLoS Medicine. 2014;11(3).
123. Aminian S, Hinckson EA. Examining the validity of the ActivPAL monitor in measuring posture and ambulatory movement in children. International Journal of Behavioral Nutrition and Physical Activity. 2012;9(1):119.
124. Ferguson T, Rowlands AV, Olds T, Maher C. The validity of consumer-level, activity monitors in healthy adults worn in free-living conditions: a cross-sectional study. International Journal of Behavioral Nutrition and Physical Activity. 2015;12(1):42.
125. Dominick GM, Winfree KN, Pohlig RT, Papas MA. Physical activity assessment between consumer-and research-grade accelerometers: a comparative study in free-living conditions. Journal of Medical Internet Research. 2016;4(3):110.
126. Tully MA, McBride C, Heron L, Hunter RF. The validation of Fitbit Zip physical activity monitor as a measure of free-living physical activity. BMC Research Notes. 2014;7(1):952.

SUMMARY

The evidence-base and importance of regular Physical Activity (PA) for children's health and well-being is becoming increasingly understood, both worldwide and in the Netherlands. PA has direct benefits for general cognitive performance, bone health and social capabilities. PA also has long term indirect health benefits via the primary prevention of overweight and obesity. In addition, children's inactivity tends to track from childhood into adolescence and adulthood. Therefore, it is of great interest and societal relevance to investigate how to effectively promote children's daily PA behavior.

Previous studies generally studied PA using either objective measurements (e.g. accelerometers) or questionnaires. The eight studies presented in this thesis address four main objectives: **1)** investigating the relationship between objectively measured PA and the subsequent development of (over)weight in children, **2)** investigating the influence of individual-level determinants (e.g. psychological determinants and socio-demographical factors) on measurements of children's PA, **3)** understanding determinants of children's outside play as reported by their parents, how these determinants interact with each other, and in which way the influence of these determinants develop over time, **4)** understanding how objectively measured factors in the physical environment relate to measurements of daily PA patterns in children, and how these PA patterns develop in transition from primary to secondary school.

Chapter 1 describes the direct and indirect benefits of regular PA in children and introduces current empirical evidence on determinants of PA at both the individual and environmental level. Subsequently, this chapter presents main challenges in measuring PA and potential determinants in the environment, and addresses potential methodological (and technological) advances regarding how these challenges can be dealt with. Finally, this chapter describes the outline of this thesis and introduces the specific studies that were performed.

Chapter 2 describes a study on the relationship between PA and the subsequent development of Body Mass Index of 4-9-year-old children. In this study, we have performed analyses based on existing objective measurements of PA (i.e. accelerometer data) carried out within the KOALA Birth Cohort Study. We found that in heavier boys and girls, an increment of 6.5 minutes of MVPA was associated with a subsequent decrease of 0.03 standard deviation BMI scores. In normal weight boys, an increment in moderate-to-vigorous PA was associated with lower BMI standard deviation score. These findings underline that promoting PA in heavier boys and girls should remain a major long-term health promotion strategy in 4-9-year-old children.

Chapter 3 describes a study on the relationship between PA enjoyment and measured PA in 9-year-old boys and girls. Here we have analyzed previously collected accelerometer data from the KOALA Birth Cohort Study. We found that children with higher scores on PA enjoyment, did not perform more daily PA. This is because the relationship differed for boys compared to girls and for children with different personality-characteristics (i.e. impulsivity). In this case, gender and impulsivity are so-called moderating factors in the relationship between PA enjoyment and PA behavior. This study therefore shows that relationships between psychosocial factors and PA behavior are not straightforward, and that information on gender and personality increases our understanding of how these factors interrelate.

The study in **chapter 4** investigated the influence of the perceived physical- and social environment on children's outside play. Here we used existing data from the 'Be Active Eat Right' study, where total duration of outside play was assessed by parental questionnaires. We found that social environmental determinants were generally stronger compared to perceived physical environmental determinants, at both five and seven years. Habit strength towards parental promotion of outside play, the presence of parental rules regarding outside play, and having physically active siblings were stable correlates of outside play. These findings demonstrated that the social environment, and especially parental rearing variables, were a strong correlate of outside play in five and seven-year-old children.

The study in **chapter 5** also focusses on determinants of outside play in the physical- and social environment. We have analyzed existing data from the KOALA Birth Cohort Study, where the duration of outside play was assessed by questionnaire. Following up on the results found in chapter 4, we investigated whether the relationship between the perceived physical environment and children's outside play was influenced by parenting influences and social capital. We found that parent-perceived accessibility to PA facilities, social capital in the neighborhood, and positive parental attitudes towards PA were associated with more minutes outside play. In contrast, concern regarding their child's PA and restriction of screen time was associated with fewer minutes outside play. The influence of the perceived environment was less important if parents did not perceive responsibility towards their child's PA levels. This means that parent's responsibility is an important moderating factor in children's outside play.

The last four chapters focused on objective measurements of factors in the physical environment related to measurements of children's PA. The study presented in **chapter 6** examined the influence of daily weather elements (e.g. rain, temperature) on children's PA patterns across the four seasons of one year, reflecting day-to-day variations over time within children. We analyzed data from an existing dataset of the Institute of PA and Nutritional Sciences in South-East Australia. Daily meteorological data was obtained from weather station registries that were closest to a child's residential location. Meteorological data was subsequently merged with daily accelerometer data. Results showed that temperature and day type (weekdays) were the strongest factors related of increased PA, followed by daily hours of solar radiation and humidity. In addition, temperature showed a strong curvilinear relationship, with optimum moderate-to-vigorous PA levels around 20-25 degrees Celsius. Apart from implications on providing infrastructure for appropriate PA on hotter days, this study also shows researchers how to retrospectively account for weather elements in future studies.

Chapter 7 presents a study investigating the relationship between PA opportunities (i.e. playability) of school environments and objectively measured afterschool PA. Here we analyzed PA by existing accelerometer data obtained by the 'Active Living' study, in Zuid-Limburg, the Netherlands. Playability of school environments was measured by systematically auditing the number of quality of playgrounds (defined by an 800-m buffer area) of 21 primary schools. Time- and distance filters were applied to understand where and when these school environment influence children's PA. Although children from schools with higher playability-scores spent more light PA and moderate-to-vigorous PA directly afterschool until 6 PM, the strength of this association attenuated at time-segments later in the evening. In addition, we found that results were strongest for children that lived within 400-m of their primary school, and no longer significant for children that lived more than 800-m from their school. These results underline the empirical importance of the quality and quantity of playgrounds in school environments. In addition, these results support that relationships between attributes of the environment and PA can be elucidated by increasing specificity of time and place.

Chapter 8 describes a study on relationships between attributes of the objective physical environment and children's afterschool PA. In this study, we have collected and analyzed accelerometer and GPS data from the PHASE-kids study in 's-Hertogenbosch, the Netherlands. This project was initiated to analyze measurements of PA in the transition from primary to secondary school and its relationship with factors in the physical environment. Based on information from both Global Positioning Systems (GPS) and Geospatial Information Systems (GIS) this study was able to study specific contexts of the afterschool time-segment such as leisure time, bicycling, walking, and organized sport participation. As children are exposed to multiple environments in the afterschool time period, this study focused on the influence of the combined home-, school-, and daily transport environment between their home and school. We found that afterschool leisure time PA was associated with environments containing more greenspace (i.e. lawns and shrubs), buildings and pedestrian paths, and with environments containing smaller home-school distances. In addition, cycling was associated with larger home-school distances and environments with more pedestrian areas and sports terrains, while fewer minutes of cycling was associated with more buildings, lawns, and pedestrian paths. Walking was associated with environments containing more agriculture, shrubs, main roads and pedestrian paths, and smaller home-school distances. Collectively, this study revealed relevant environmental determinants of afterschool leisure time and transport-related PA by combining accelerometer, GPS and GIS data.

Chapter 9 describes a longitudinal study on the development of PA patterns in the transition between primary and secondary school. Here we used data from the PHASE-kids study and selected children with accelerometer and GPS measurements collected both in the last year of primary school and first year of secondary school. Based on information from GPS and GIS data, this study was able to specify multiple contexts: participant's residence, school, sports grounds, and other places. In addition, analyses were separated for the time-segments before school, during school, after school and weekend days. We found that light PA and moderate-to-vigorous PA declined, especially after school and during weekends. The major components that decreased from primary to secondary school were 1) increased sedentary time at the residence, 2) decreased light PA at sports grounds, and 3) decreased light PA and moderate-to-vigorous PA at other locations. In addition, transport-related activity significantly increased during weekdays, and stronger increases were found for children with greater increases in distance from the residence to their school. This study provided in-depth insights of where, and at which time periods changes in children's PA patterns occur.

Finally. **chapter 10** discusses the findings of the studies presented in this thesis in broader perspective, and highlights some methodological and theoretical considerations in the interpretation of both results presented in this thesis, as well as other comparable PA studies. Furthermore, this chapter presents recommendations for health promotors and policy makers involved in PA promotion, and recommends future directions for researchers involved in children's PA.

The main conclusion from the studies presented in this thesis is that reliable objective measurements of children's PA and analyses in place and time, enable important steps to be taken in understanding how children's PA patterns are influenced by specific determinants in the social and physical environment.

SAMENVATTING

De rol van dagelijks bewegen ten behoeve van de gezondheid en het welbevinden van kinderen wordt tegenwoordig steeds beter onderkend, zowel in Nederland als internationaal. Voorbeelden daarvan zijn de wereldwijde beweegrichtlijnen van de wereld gezondheidsorganisatie (WHO) en het hernieuwde advies van de Nederlandse Gezondheidsraad omtrent dagelijks bewegen. Voldoende bewegen wordt bij kinderen in verband gebracht met bijvoorbeeld sterkere spieren en botten, maar ook mentale voordelen zoals betere cognitieve prestaties en sociale vaardigheden. Daarnaast speelt dagelijks bewegen een belangrijke rol in de preventie van overgewicht en obesitas. Daarnaast blijkt dat de meeste kinderen die onvoldoende bewegen, dit op latere leeftijd moeilijk kunnen veranderen. Daarom is het belangrijk om onderzoek te doen naar op welke wijze we het beweeggedrag van kinderen succesvol kunnen bevorderen.

Wat opvalt in eerder onderzoek is dat er gebruik wordt gemaakt van verschillende technieken om de hoeveelheid bewegen in kaart te brengen; objectieve metingen (bijvoorbeeld accelerometers) en vragenlijsten. Dit proefschrift beschrijft een verzameling van acht studies die gericht zijn op het beweeggedrag van kinderen. Specifieker omvat dit proefschrift een viertal doelstellingen: **1)** het onderzoeken van de relatie tussen de hoeveelheid objectief gemeten bewegen en de ontwikkeling van (over)gewicht op latere leeftijd, **2)** inzicht verkrijgen in specifieke determinanten op individueel niveau (bijvoorbeeld psychologische determinanten en sociaal-demografische factoren) van objectief gemeten beweeggedrag, **3)** begrijpen van determinanten die een rol spelen in de hoeveelheid buiten spelen dat ouders rapporteren, hoe deze determinanten zich tot elkaar verhouden, en op welke manier de invloed van deze determinanten zich ontwikkelt op latere leeftijd, **4)** begrijpen hoe objectief gemeten onderdelen in de fysieke omgeving gerelateerd zijn aan metingen van dagelijkse beweegpatronen van kinderen en hoe deze beweegpatronen zich ontwikkelen in de overgang van basisschool naar het voortgezet onderwijs.

Hoofdstuk 1 beschrijft een overzicht van directe- en indirecte voordelen van dagelijks bewegen op de gezondheid en het welbevinden van kinderen, en introduceert wat er momenteel bekend is in de literatuur over invloeden van beweeggedrag op zowel individueel niveau als in de omgeving. Daarnaast beschrijft dit hoofdstuk belangrijke uitdagingen die momenteel spelen bij het meten van beweeggedrag en de omgeving en worden recente (technologische) ontwikkelingen in het objectief meten van beweeggedrag geïntroduceerd. Tenslotte beschrijft dit hoofdstuk de inhoud en achtergrond van de studies die zijn uitgevoerd in het kader van dit proefschrift.

Hoofdstuk 2 beschrijft een studie naar de relatie tussen de hoeveelheid beweeggedrag en de ontwikkeling van de Body Mass Index (BMI) op latere leeftijd, bij vier- tot negenjarige kinderen. In dit onderzoek hebben we gebruik gemaakt van bestaande metingen van beweeggedrag (met behulp van accelerometers) bij kinderen van het KOALA-geboortecohort. In dit onderzoek vonden we dat bij kinderen die aan het begin van de studie zwaarder waren, een toename van 6,5 minuut matig-tot-intensief beweeggedrag gepaard ging met een afname van 0.03 BMI standaarddeviatie scores op latere leeftijd. Bij jongens die aan het begin van de studie een normaal gewicht hadden, was een toename van matig-tot-intensief beweeggedrag ook gerelateerd aan een afname van BMI op latere leeftijd. Deze resultaten laten zien dat toenames in het beweeggedrag directe voordelen heeft voor de BMI op latere leeftijd, vooral voor iets zwaardere kinderen. Daarom moet het bevorderen van beweging een belangrijk speerpunt blijven in de primaire preventie van overgewicht en obesitas.

Hoofdstuk 3 beschrijft een studie naar determinanten van beweeggedrag op individueel niveau, en dan specifiek de relatie tussen beweegplezier die een kind ervaart en het gemeten beweeggedrag bij negenjarige kinderen. In dit onderzoek zijn er gegevens verzameld en analyses uitgevoerd op een dataset van accelerometer gegevens bij kinderen van het KOALA-geboortecohort. De resultaten laten zien dat kinderen die hoger scoren op beweegplezier niet actiever zijn op een gemiddelde dag. De relatie hiertussen verschilt namelijk voor jongens ten opzichte van meisjes en ook voor kinderen met verschillende persoonlijkheid (i.e. impulsiviteit). In dit geval zijn geslacht en impulsiviteit dus zogenaamde moderatoren in de relatie tussen beweegplezier en beweeggedrag. Deze studie laat zien dat belangrijke psychosociale factoren niet direct voor alle kinderen in verband te brengen zijn met de hoeveelheid dagelijks bewegen en dat informatie met betrekking tot geslacht en persoonlijkheid helpt hier meer inzicht in te krijgen.

Hoofdstuk 4 beschrijft een studie naar de invloed van de ervaren fysieke- en sociale omgeving op het buiten spelen van kinderen. We hebben hier gebruik gemaakt van bestaande gegevens van het 'Lekker Bewegen Goed Eten' onderzoek, waarbij de totale duur van buiten spelen door ouders werd aangegeven in een vragenlijst. Hieruit kwam naar voren dat de sociale omgeving een sterkere rol speelt dan de fysieke omgeving in het buiten spelen van kinderen, op zowel vijf- als zevenjarige leeftijd. Gewoonten van ouders rondom het stimuleren van buiten spelen en het hanteren van regels, en de aanwezigheid van stimulans van actieve broertjes of zusjes waren belangrijke factoren. Dit onderzoek laat zien dat de sociale omgeving, en dan vooral factoren in de opvoeding, gerelateerd zijn aan de hoeveelheid buiten spelen van vijf- tot zevenjarige kinderen.

De studie in **hoofdstuk 5** focust ook op de invloed van de ervaren fysieke en sociale omgeving op het buiten spelen van kinderen. We hebben hier gebruik gemaakt van bestaande vragenlijstgegevens van het KOALA-geboortecohort, waarin de totale duur van buiten spelen door ouders werd aangegeven. In navolging op de resultaten in hoofdstuk 4, is er onderzocht in hoeverre de relatie tussen de ervaren fysieke omgeving en het buiten spelen beïnvloed wordt door opvoedings-gerelateerde factoren en sociale verbondenheid. De nabijheid van speelvoorzieningen, sociale verbondenheid in de buurt en positieve attitudes van ouders ten opzichte van het buiten spelen ging gepaard met meer buiten spelen. Bezorgdheid ten opzichte van de hoeveelheid beweging van hun kind en beperking van zittend gedrag (bijvoorbeeld TV kijken) waren gerelateerd aan minder buiten spelen. Daarnaast waren factoren van de ervaren omgeving minder sterk wanneer ouders zich niet verantwoordelijk voelden voor het beweeggedrag van hun kind. Dit betekent dat de mate van verantwoordelijkheid die ouders ervaren een belangrijke modererende factor is in het buiten spelen van kinderen.

De laatste vier hoofdstukken van dit proefschrift beschrijven studies naar objectief gemeten factoren van de fysieke omgeving in relatie tot het gemeten beweeggedrag van kinderen. **Hoofdstuk 6** beschrijft een onderzoek naar de invloed van dagelijkse weersomstandigheden (bijvoorbeeld regen of temperatuur) op het beweeggedrag van kinderen. Er werd gebruik gemaakt van meerdere herhaalde metingen (met behulp van accelerometers) verspreid over alle seizoenen van één jaar in zuidoost Australië. Gegevens met betrekking tot weersomstandigheden werden verzameld van weerstations dichtbij het huisadres van kinderen. Die gegevens werden vervolgens gekoppeld aan de metingen van het beweeggedrag. In deze studie vonden we dat temperatuur en dag van de week (weekdagen versus weekenddagen) het sterkst gerelateerd waren aan beweeggedrag, gevolgd door de hoeveelheid zonneschijn en luchtvochtigheid. De optimale temperatuur voor matig-tot-intensief beweeggedrag lag tussen de 20 en 25 graden; bij hogere temperaturen daalde de duur en intensiteit van bewegen aanzienlijk. Behalve de implicaties voor beweegstimulering laat deze studie zien hoe toekomstige studies, gebruik makend van objectieve meetmethoden, rekening kunnen houden met de invloed van dagelijkse weersomstandigheden.

Hoofdstuk 7 beschrijft een studie naar de relatie tussen de beweegvriendelijkheid van de schoolomgeving en naschools beweeggedrag van kinderen. Er werd gebruikt gemaakt van een bestaande dataset van accelerometer gegevens in het 'Active Living' onderzoek. Beweegvriendelijkheid werd gemeten door het aantal en de kwaliteit van speelvoorzieningen te observeren in systematische wijkscans, in een straal van 800 meter

rondom de 21 deelnemende basisscholen in Zuid-Limburg. In deze studie werd allereerst gevonden dat kinderen actiever waren in schoolomgevingen met een hogere beweegvriendelijkheid. Deze relatie was het sterkst bij kinderen die binnen een straal van 800 meter van hun school woonden. Tijd-specifieke analyses lieten zien dat de invloed van de beweegvriendelijkheid het sterkst was in de tijdsperiode direct na school tot 18u. Deze studie toont bovendien aan dat de beweegvriendelijkheid van de schoolomgeving bijdraagt aan de hoeveelheid naschools beweeggedrag en geeft aanknopingspunten waar en wanneer beweegactiviteiten plaats kunnen vinden. Daarnaast hebben we in dit onderzoek toekomstige onderzoekers geadviseerd om kritisch te kijken in welke tijdsperiode en op welke locaties de relaties tussen omgeving en gedrag zich het sterkst manifesteren.

In **hoofdstuk 8** is een studie beschreven naar de relatie tussen onderdelen van de fysieke omgeving en naschools beweeggedrag van kinderen. Er zijn gegevens verzameld met behulp van accelerometers en GPS meters en er werden analyses uitgevoerd in het kader van het PHASE-kids project. Het beweeggedrag werd gemeten bij kinderen in groep acht van verschillende basisscholen in 's-Hertogenbosch. Een jaar later werden dezelfde kinderen opnieuw gemeten; nu in de eerste klas van het voorgezet onderwijs. Gebaseerd op gegevens van Global Positioning Systems (GPS meters) en Geografische Informatie Systemen (GIS gegevens) kon deze studie nog specifieker kijken naar contexten waarin naschools beweeggedrag plaatsvindt, bijvoorbeeld sport, fietsen, wandelen en buiten spelen. Omdat beweeggedrag na schooltijd wordt beïnvloed door meerdere omgevingen, is er in deze studie gekeken naar de gecombineerde thuisomgeving, schoolomgeving, en de omgeving rondom de dagelijkse route tussen school en huis. In deze studie hebben we gevonden dat naschools buiten spelen gerelateerd was aan omgevingen met meer groen (bijvoorbeeld struiken en gras), meer gebouwen, meer voetpaden en kleinere afstanden tussen school en huis. Daarnaast was naschools fietsen gerelateerd aan de aanwezigheid van meer fietspaden in de omgeving, meer sportterreinen, minder gebouwen, minder gras en minder voetpaden. Naschools wandelen was gerelateerd met meer agrarisch gebied in de omgeving, meer struiken, meer autowegen, meer voetpaden en kleinere afstanden tussen school en huis. Deze studie laat zien dat met behulp van objectieve accelerometer, GPS en GIS gegevens een beter beeld te verkrijgen is van omgevingskenmerken die een stimulerende invloed hebben op het naschools beweeggedrag van kinderen.

Hoofdstuk 9 beschrijft een studie naar de ontwikkeling van objectief gemeten beweegpatronen in de overgang van basisschool naar het voortgezet onderwijs. Er werd hier opnieuw gebruikt gemaakt van gegevens van het PHASE-kids project. In deze studie is er met behulp van accelerometer, GPS en GIS gegevens gekeken naar specifieke beweegpatronen zoals bewegen in huis, op school, op de sportvereniging en op andere plaatsen. De ontwikkelingen in deze beweegpatronen zijn apart bekeken in de perioden voor- tijdens-, na schooltijd en in het weekend. Uit de resultaten komt naar voren dat kinderen aanzienlijk minder gaan bewegen wanneer ze naar het voortgezet onderwijs gaan, voornamelijk in de periodes na school en in het weekend. Dit komt vooral tot uiting in een toename van zittend gedrag na school op de thuislocatie, een afname van licht intensief beweeggedrag op sportverenigingen, en een afname van beweeggedrag op andere locaties dan hierboven beschreven. Daarentegen werd er een gemiddelde toename van actief transport gevonden gedurende weekdagen. Deze toename was sterker voor kinderen die op een grotere afstand van hun school woonden. Deze uitkomsten geven een beter inzicht in de ontwikkelingen van beweegpatronen van kinderen in de overgang van de basisschool naar het voortgezet onderwijs, en geven daarnaast aanknopingspunten voor beweegstimulering na schooltijd en in het weekend.

Tenslotte worden in **hoofdstuk 10** van dit proefschrift de belangrijkste resultaten gepresenteerd en in een breder perspectief geplaatst. Daarnaast worden er methodologische en theoretische overwegingen beschreven die relevant zijn voor zowel de interpretatie van de resultaten in dit proefschrift als voor vergelijkbare studies in dit vakgebied. Bovendien worden in dit hoofdstuk ook aanbevelingen voor zowel gezondheidsprofessionals als onderzoekers gepresenteerd om beweegstimulering verder te bevorderen.

De belangrijkste conclusie die uit dit proefschrift getrokken kan worden is dat door middel van betrouwbare objectieve metingen, beweegpatronen van kinderen beter in beeld gebracht kunnen worden. Wanneer die gegevens gecombineerd worden met informatie die aangeeft waar en wanneer beweegpatronen plaatsvinden, worden er belangrijke stappen gezet in het begrijpen van specifieke invloeden op beweegpatronen in de sociale en fysieke omgeving.

VALORIZATION ADDENDUM

The current chapter describes the societal value and relevance of the work presented in this thesis. This will be described in terms of the relevance of study results for specific target groups. Also the dissemination of the results and products presented in this thesis will be described.

Relevance of the results presented in this thesis

The importance of regular Physical Activity (PA) for children's health and well-being is well understood, both worldwide and in the Netherlands (1). Increased PA is related to various benefits for children's general health and well-being. For example, several studies have indicated that inactivity is directly linked with various detrimental consequences for health and well-being, such as cardiovascular risk factors, bone health, general cognitive functioning, and social capabilities of children (2-5). In addition, PA may also be indirectly beneficial with respect to the primary prevention of overweight and obesity. As inactivity tends to track from childhood to adolescence and even to adulthood (6, 7), promoting PA is a major health promotion target in children.

Given the multi-dimensional short- and long term benefits of PA and the increased need for policies informed by evidence-based information, knowledge about how to effectively increase children's PA levels is of interest to multiple stakeholders such as researchers, policy makers at municipalities, health promotion professionals, school teachers, and parents. Accurate and reliable objective measurements of the frequency, intensity, and duration of PA over longer time periods (e.g. using accelerometers) is essential in identifying children that are insufficiently active and is an essential step in understanding how to increase these PA levels (8). In addition, effectively promoting children's PA levels also requires knowledge about determinants of PA. Several conceptual frameworks propose that besides individual-level factors (e.g. motivation, personality traits), PA is influenced by various layers of environmental factors (9). This may be especially relevant to municipalities and designers of public (urban) spaces. The relative influence of these factors however depend on the type of PA performed. For example, while some attributes of the physical environment may act as determinants of active transport, these attributes may be unsuccessful in influencing PA performed at school. This means that increased specificity of the type of PA (i.e. the PA context) is necessary to understand how PA can be influenced (10). The studies presented in this thesis provide indications for determinants of PA at both the individual and environmental level, which may in turn be used to successfully promote PA in various contexts (e.g. outside play, afterschool PA, sports participation, active transport).

The innovative techniques presented in chapters 6, 7, 8 and 9 are examples of the possibilities that arise when combining objective PA and environmental data from multiple sources or sensors. Namely, in these chapters, we have combined accelerometer data with registries of weather elements (chapter 6), school's time schedules (chapter 7) and combined GPS and GIS data (chapters 8 and 9). By doing so, relevant additional insights were obtained on determinants of PA in several social- and physical contexts, as

these methodologies enable researchers to investigate time-specific and location-specific analyses between the environment and PA behavior. Driven by fast-developing technological innovations and interest in the consumer market, collecting continuous streams of objective biometric data (e.g. activity and sleep patterns, blood glucose, blood pressure) becomes increasingly affordable. These technological innovations enlarge the possibilities to increase our understanding of specific relationships between PA and the environment, and enable us to combine data from multiple sensors to investigate under which circumstances the data from these sensors deviate or correlate. Most importantly however, these fast-developed biometric sensors should be extensively validated both in research-level as well as in consumer-level products, in order to avoid researchers as well as consumers to interpret these findings based on erroneous data.

Dissemination of results and products

The main innovative aspects of the results presented in this thesis are the investigation of PA within the specific social and organizational contexts, and the integration of objective measurements from multiple sources (i.e. accelerometers, registries of weather stations, global positioning systems and geographic information systems). In addition, the studies have additional innovative aspects in focusing for example on dynamics of PA in important phases in the development of childhood (i.e. the transition between primary and secondary school) and relationships with associated risk factors (i.e. the adiposity rebound period).

Empirical evidence is increasing regarding the influence of the publically accessible physical environment on for example children's leisure time PA and active transport. Therefore, results from studies using innovative methodology as presented in chapter 7, 8 and 9 may be of special interest to municipalities that attempt to create and facilitate supporting environments, incorporating multiple policy sectors such as urban design, transport, safety, and health. GPS and GIS methodologies are also suited to intuitively grasp and visually inspect mobility patterns of individual persons in their environment and observe trends across the day. Therefore these techniques can be integrated in innovation-platforms involving for example several municipality-sectors, universities, and commercial parties such as construction or transport companies. These innovation-platforms can systematically implement and analyze small-scaled natural experiments in publically accessible environments, targeting for example PA behaviors. Chapters 8 and 9 of this thesis have been made possible by continuous collaboration between the municipality of 's-Hertogenbosch and Maastricht University. Active collaboration with the municipality facilitated the recruitment of participants, data collection, and data analyses. We have planned additional meetings with various sectors of the municipality in the near future to further disseminate specific knowledge based on chapters 8 and 9, and to prioritize additional small-scaled analyses based on questions raised in interaction with the municipality. Another example of such collaboration between municipality-sectors, commercial parties and universities is the recently developed A2health study. This study evaluates an infrastructural change where main roads will be replaced by greenspaces and

cycling paths, involving the surrounding neighborhoods and its associated public health services. Also, Maastricht University, Utrecht University, the Fontys University of Applied Sciences Sport Eindhoven, and the Dutch ministry of infrastructure and environment were involved in this project. Relationships between the environment and PA will be studied in the A2Health study with techniques that are in line with the methodologies applied in chapters 7, 8 and 9.

However, the strength of the innovative methodology presented in this thesis is limited to the quality or precision of the GIS data at hand. As the quality of GIS data may differ between municipalities, standardization and national registries of highly specific Geospatial information is warranted. With this highly specific Geospatial information, results from studies as presented in 8 and 9 of this thesis may be easier generalized and disseminated to other municipalities. This also provides opportunities to combine accelerometer and GPS datasets across the Netherlands, or perhaps even internationally. By doing so, objective PA patterns can be studied in more diverse environmental, organizational, social, and socio-demographical contexts. An example of this combination of datasets is the international children's accelerometry database, which pooled accelerometer measurements from 20 countries worldwide (11).

Combined accelerometer and GPS methodologies only contain objective information on participant's movement or location. However, the integration of subjective data that relates to participant's perceptions of the built environment (e.g. perceptions of aesthetics, attractiveness, safety, functionality, or vicinity) provides important additional insights in environment-behavior relationships. The integration of these subjective measurements may be especially feasible when using ecological momentary assessment techniques, by which a respondent can report subjective information (e.g. perceptions or affect) repeatedly across the day at certain pre-defined time points (12). In this way, subjective information will be reported close in time to the actual experience, and can be subsequently aligned with objective information regarding children's activity and location. In terms of valorization, subjective data regarding perceptions of public spaces combined with objective data regarding the spatial location or travel patterns is highly relevant for municipalities, as these data can directly highlight where, when and in which domain (e.g. aesthetics, safety, functionality) important changes to the publically accessible physical or social environment can be made.

The outcomes of the work presented in this thesis have been disseminated through various channels. Results were disseminated through presentations, media, readings and publications in national and international journals. In addition, the methodological approach and accompanied results were presented at several national- and two international conferences (i.e. oral presentations during the 'International Conference of Diet and Activity Methods' and during the annual conference of the 'International Society of Behavioral Nutrition and Physical Activity'). Also, outcomes and techniques presented in this thesis have been used for educational purposes, for example in the Master of Sports and Physical Education at Fontys University of Applied Sport Sciences and in the

Bachelor Health Sciences at Maastricht University. The activities, products and innovations presented in this thesis led to further collaboration with national institutes (i.e. School of Sports Studies at Fontys University of Applied Sciences Sport Eindhoven, the Research group Healthy Lifestyle in a Supporting Environment at the Hague University of Applied Sciences, and the Department at Human Geography and Spatial Planning at Utrecht University) and international institutes (i.e. the Institute for Physical Activity and Nutrition at Deakin University, Melbourne, Australia).

References

1. Gezondheidsraad. Beweegrichtlijnen 2017. Den Haag: Gezondheidsraad 2017; publicatienr. 2017/08.
2. Janssen I, LeBlanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. International Journal of Behavioral Nutrition and Physical Activity. 2010;7(40):1-16.
3. Boreham CAG, McKay HA. Physical activity in childhood and bone health. British Journal of Sports Medicine. 2011;45.
4. Biddle SJ, Asare M. Physical activity and mental health in children and adolescents: a review of reviews. British Journal of Sports Medicine. 2011.
5. Sibley BA, Etnier JL. The relationship between physical activity and cognition in children: a meta-analysis. Pediatric Exercise Science. 2003;15(3):243-56.
6. Telama R. Tracking of physical activity from childhood to adulthood: a review. Obesity Facts. 2009;2(3):187-95 .
7. Kristensen PL, Møller N, Korsholm L, Wedderkopp N, Andersen LB, Froberg K. Tracking of objectively measured physical activity from childhood to adolescence: the European youth heart study. Scandinavian Journal of Medicine & Science in Sports. 2008;18(2):171-8.
8. Armstrong N, Welsman JR. The physical activity patterns of European youth with reference to methods of assessment. Sports Medicine. 2006;36(12):1067-86.
9. Kremers SP, De Bruijn GJ, Visscher TL, Van Mechelen W, De Vries NK, Brug J. Environmental influences on energy balance-related behaviors: a dual-process view. International Journal of Behavioral Nutrition and Physical Activity. 2006;3(1):9.
10. Giles-Corti B, Timperio A, Bull F, Pikora T. Understanding physical activity environmental correlates: increased specificity for ecological models. Exercise and Sport Sciences Reviews. 2005;33(4):175-81.
11. Sherar LB, Griew P, Esliger DW, Cooper AR, Ekelund U, Judge K, Riddoch C. International children's accelerometry database: design and methods. BMC Public Health. 2011;11:485.
12. Spook JE, Paulussen T, Kok G, van Empelen P. Monitoring dietary intake and physical activity electronically: feasibility, usability, and ecological validity of a mobile-based ecological momentary assessment tool. Journal of Medical Internet Research. 2013;15(9):214.

APPENDICES

Appendix 1: Supplemental Material Chapter 4

Table S1: Items assessing family and physical environment with regard to child outside play engagement

Construct	Construct properties	Construct description	Translated item	Response scale	Dichotomous scale
Family environment					
Parental attitude	Cronbach's alpha 0.86	Parental attitude to improve child engagement in outside play	I think it is important for my child to improve child engagement in outside play	1=totally disagree to 5= totally agree	-
	Scale range 1-5		I think it is good for my child to improve child engagement in outside play	1=totally disagree to 5=totally agree	-
			I think it is healthy for my child to improve child engagement in outside play	1=totally disagree to 5=totally agree	-
Family attitude	Cronbach's alpha 0.85	Family attitude to improve child engagement in outside play	I think my child should increase engagement in outside play	1=totally disagree to 5=totally agree	-
	Scale range 1-5		My partner thinks our child should increase engagement in outside play	1=totally disagree to 5=totally agree	-
			My family thinks my child should increase engagement in outside play	1=totally disagree to 5=totally agree	-
Perceived difficulty	-	Parental perception of their difficulties in improving child engagement in outside play	It is difficult to let my child engage in more outside play	1=totally agree to 5=totally disagree	1=agree (strongly agree, agree), 0=not agree (not agree/not disagree, disagree, strongly disagree)
Self confidence	-	Parental confidence in their own ability to improve child engagement in outside play	I can let the child engage in more outside play	1=totally agree to 5=totally disagree	1=agree (strongly agree, agree), 0=not agree (not agree/not disagree, disagree, strongly disagree)

Intention to improve	-	Parental intention to improve child engagement in outside play	I am planning to improve my child's engagement in outside play	1=totally disagree to 5=totally agree	1=agree (strongly agree, agree), 0=not agree (not agree/not disagree, disagree, strongly disagree)
Habit strength	-	Parental perception improving child engagement in outside play is a habit for them	It is a habit for me to let my child engage in more time of outside play	1=totally disagree to 5=totally agree	1=agree (strongly agree, agree), 0=not agree (not agree/not disagree, disagree, strongly disagree)
Monitoring	-	Parental monitoring of child engagement in outside play	To what extent do you monitor your child's engagement in outside play?	1=never to 5=always	1=frequent (often, always), 0=not frequent (sometimes, seldom, never)
Child autonomy	-	Parental control towards child outside play	How often can your child decide for themselves to play outside?	1=never to 5=always	1=frequent (often, always), 0=not frequent (sometimes, seldom, never)
Active encouragement	-	Degree of parental encouragement towards their child's outside play	How often do you tell your child to play outside?	1=never to 5=always	1=frequent (often, always), 0=not frequent (sometimes, seldom, never)
Modeling parent	-	Physical activity behavior of the parent	How many days per week are you physically active?	0 to 7	-
Modeling partner	-	Physical activity behavior of the partner from the parent	How many days per week is your partner physically active?	0 to 7	-
Modeling siblings	-	Physical activity behavior of siblings	How many days per week are siblings physically active?	0 to 7	-
Rules		Presence of rules parents report with regard to child outside play	Do you have rules in your home about your child's outside play?	1=yes, 0=no	1=yes, 0=no
Physical environment					
Traffic business	-	Parent perceived presence of traffic	In the neighborhood of our family there is a lot of traffic	1=totally disagree to 5=totally agree	1=agree (strongly agree, agree), 0=not agree (not agree/not disagree, disagree, strongly

					disagree)
Safety perception during daytime	-	Parent perceived safety regarding outside play during daytime	In the neighborhood of our family it is safe for children to play during the daytime	1=totally disagree to 5=totally agree	1=agree (strongly agree, agree), 0=not agree (not agree/not disagree, disagree, strongly disagree)
Safety during the evening	-	Parent perceived safety regarding outside play in the evening	In the neighborhood of our family it is safe for children to play in the evening	1=totally disagree to 5=totally agree	1=agree (strongly agree, agree), 0=not agree (not agree/not disagree, disagree, strongly disagree)
Presence of sidewalks	-	Parent perceived presence of sidewalks for their child to play on	In the neighborhood of our family, the majority of the streets have sidewalks to play on	1=totally disagree to 5=totally agree	1=agree (strongly agree, agree), 0=not agree (not agree/not disagree, disagree, strongly disagree)
Friendliness for children	-	Parent perceived child-friendliness of their neighborhood	The neighborhood of our family is pleasant to reside with children	1=totally disagree to 5=totally agree	1=agree (strongly agree, agree), 0=not agree (not agree/not disagree, disagree, strongly disagree)
Attractiveness for children	-	Parent perceived attractiveness of their neighborhood for families with children	The neighborhood of our family is attractive for families with children	1=totally disagree to 5=totally agree	1=agree (strongly agree, agree), 0=not agree (not agree/not disagree, disagree, strongly disagree)
Opportunities for outside play	-	Parent perceived opportunities of the neighborhood for their child to play	In the neighborhood of our family there is sufficient opportunities for my child to play	1=totally disagree to 5=totally agree	1=agree (strongly agree, agree), 0=not agree (not agree/not disagree, disagree, strongly disagree)
Safety of outside play without supervision	-	Parent perceived safety regarding outside play without supervision	In the neighborhood of our family it is safe to play outside without supervision of an adult	1=totally disagree to 5=totally agree	1=agree (strongly agree, agree), 0=not agree (not agree/not disagree, disagree, strongly disagree)

Appendix 2: Supplementary material chapter 5

Table S1. Characteristics of attributes of the perceived physical environment and moderators in the relationship between the perceived physical environment and child outside play.

Construct	Description / Items	Cronbach's alpha	Mean (SD)
Potential moderators			
Attitude	5-item mean score; usefulness, importance, healthiness, pleasantness, tediousness of child physical activity	0.77	4.5 (0.5)
Perceived responsibility	2-item mean score; perceived responsibility regarding child amount of physical activity and limit of physical activity	0.93	3.6 (0.9)
Concern	3-item mean score; concern regarding child lack of physical activity, diet for weight management, getting overweight	0.68	1.3 (0.5)
Restriction	6-item mean score; if not regulated child would watch too much TV/not enough physical activity, I want to be sure that my child does not watch too much TV/plays too many computer games, I reward good behavior of my child with TV or computer games, I deliberately keep my child away from the TV or computer	0.59	3.0 (0.7)
Pressure	4-item mean score; stimulation of PA against child will, parental pressure towards child getting as much active transport as possible, parents make sure that child is sufficiently active	0.57	3.7 (0.6)
Monitoring	2-item mean score; parental monitoring of TV/computer games, and physical activity	0.64	3.9 (0.8)
Social capital	5-item mean score; willingness to help each other in neighborhood, presence of community, trust in neighborhood, getting along in neighborhood, sharing of norms and values	0.87	3.8 (0.6)
Attributes of the perceived physical environment			
Accessibility	7-item mean score; number of facilities for PA within 10 minutes walking distance from forest, school, playground,	n.a.	3.4 (0.5)

	playing field (unpaved), gym or facility for exercise, swimming pool		
Traffic safety	4-item mean score; speed of traffic (max 30kmph), exhausts, ability of child outside play regarding traffic, compliance with speed limit	0.74	3.3 (1.0)
Functionality	6-item mean score; availability of footpaths and stairs, maintenance of footpaths, separation of footpaths from streets, availability of cycling paths, separation of cycle paths from streets, availability of different routes	0.64	3.0 (0.8)
Attractiveness	7-item mean score; availability of green, amount of litter, presence of residential blocks, presence of detached houses, presence of abandoned houses, amount of noise, amount of dog feces	0.66	3.9 (0.6)
Satisfaction	3-item mean score; satisfaction with opportunities to play outside, satisfaction with opportunities to walk, satisfaction with opportunities to cycle	0.85	3.8 (0.9)

Note: all constructs have 5-item response scales

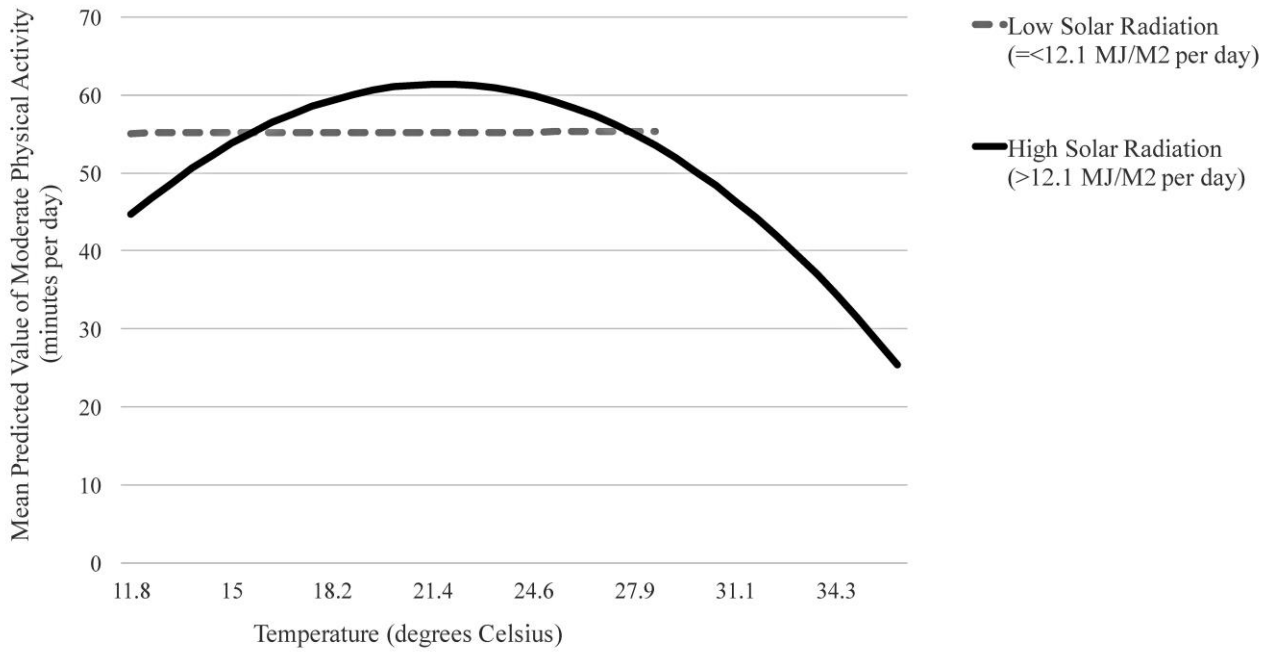
Appendix 3: Supplementary material chapter 6

Supplementary Digital Content 1: Relationship between weather elements and sedentary time and physical activity of light intensity (*n*=4599 days, *n*=307 children)

	Sedentary time	**Light PA**
	std. B (95%CI)	**std. B (95% CI)**
	-2 restricted log likelihood = 3398	-2 restricted log likelihood = 9056
Rainfall (0.01–7.8 mm per day versus no rainfall)	**-0.051 (-0.076 to -0.026)**	**0.097 (0.050 to 0.143)**
Rainfall (7.9–46.0 mm per day versus no rainfall)	**-0.040 (-0.078 to -0.003)**	**0.119 (0.048 to 0.190)**
Humidity	**0.019 (0.002 to 0.035)**	-0.004 (-0.035 to 0.027)
Day length	0.011 (-0.049 to 0.070)	0.003 (-0.113 to 0.120)
Temperature	-0.082 (-0.171 to 0.006)	**0.047 (0.006 to 0.088)**
Temperature squared	**0.094 (0.014 to 0.174)**	*
Solar Radiation exposure	**-0.027 (-0.045 to -0.009)**	0.033 (-0.001 to 0.066)
Day type (weekday versus weekend day)	**-0.128 (-0.154 to -0.103)**	**0.121 (0.074 to 0.168)**
Gender (boys versus girls)	**-0.128 (-0.186 to -0.070)**	0.046 (-0.069 to 0.161)
Age in years	0.008 (-0.022 to 0.039)	0.027 (-0.034 to 0.087)
Body Mass Index	-0.021 (-0.048 to 0.006)	**0.070 (0.017 to 0.123)**

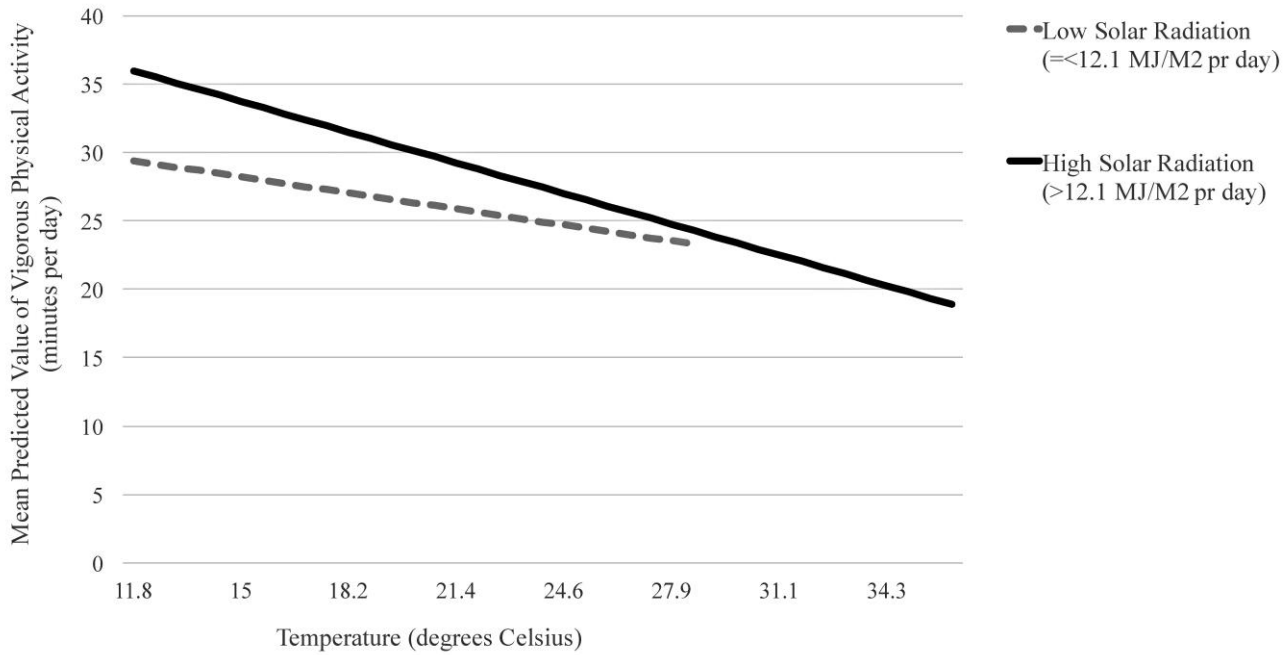
Table shows fixed effects (as standardized regression coefficients (std. B) with 95% confidence intervals (CI) from linear mixed models, with a random intercept for each child, and a repeated term for each child across each repeated observation, with autoregressive covariance structure. *: Temperature squared was excluded from this model as it was not statistically significant. Bolded text indicates significant at p<0.05.

Supplementary Digital Content 2: Relationship between Temperature and Moderate Physical Activity, moderated by solar radiation



Mean Unstandardized Predicted Values of Moderate Physical Activity were adjusted for rainfall, humidity, day length, day type, gender, age, and BMI. In the low solar radiation subgroup, quadratic term of temperature was omitted from the model as it was no longer statistically significant in subgroup analyses. For Moderate Physical Activity p-value temperature < 0.01; p-value temperature^2 < 0.01. For Low solar radiation p-value temperature = 0.94 (temperature^2 omitted from model). For High solar radiation p-value temperature < 0.29; p-value temperature^2 < 0.01.

Supplementary Digital Content 3: Relationship between Temperature and Vigorous Physical Activity, moderated by solar radiation



Mean Unstandardized Predicted Values of Vigorous Physical Activity were adjusted for rainfall, humidity, day length, day type, gender, age, and BMI. Quadratic terms of temperature for both subgroups were omitted from the model as they were no longer statistically significant in subgroup analyses. For Low solar radiation p-value temperature < 0.01 (temperature^2 omitted from model). For High solar radiation p-value temperature < 0.01 (temperature^2 omitted from model).

Supplementary Digital Content 4: Relationship between weather elements and physical activity, and interactions between weather elements (*n*=4599 days, *n*=307 children)

	Moderate PA	**Vigorous PA**
	std. B (95%CI)	**std. B (95% CI)**
	-2 restricted log likelihood = 10939	-2 restricted log likelihood = 10727
Rainfall (0.01–7.8 mm per day versus no rainfall)	**0.077 (0.020 to 0.134)**	0.051 (-0.006 to 0.108)
Rainfall (7.9–46.0 mm per day versus no rainfall)	-0.064 (-0.149 to 0.022)	-0.009 (-0.094 to 0.077)
Humidity	**-0.045 (-0.083 to -0.007)**	**-0.057 (-0.095 to -0.020)**
Day length	-0.112 (-0.240 to 0.017)	**-0.154 (-0.281 to -0.028)**
Temperature	-0.077 (-0.345 to 0.191)	-0.259 (-0.524 to 0.007)
Temperature squared	-0.003 (-0.280 to 0.274)	0.074 (-0.201 to 0.349)
Solar Radiation exposure	**0.155 (0.107 to 0.204)**	**0.148 (0.100 to 0.196)**
Day type (weekday versus weekend day)	**0.438 (0.380 to 0.495)**	**0.330 (0.274 to 0.386)**
Gender (boys versus girls)	**0.522 (0.410 to 0.633)**	**0.531 (0.396 to 0.666)**
Age in years	**-0.109 (-0.168 to -0.051)**	**-0.049 (-0.120 to 0.022)**
Body Mass Index	*	**-0.102 (-0.163 to -0.040)**
Solar * Temperature	**-0.390 (-0.602 to -0.177)**	**-0.492 (-0.703 to -0.280)**
Solar * Temperature squared	**0.255 (0.044 to 0.467)**	**0.372 (0.162 to 0.582)**

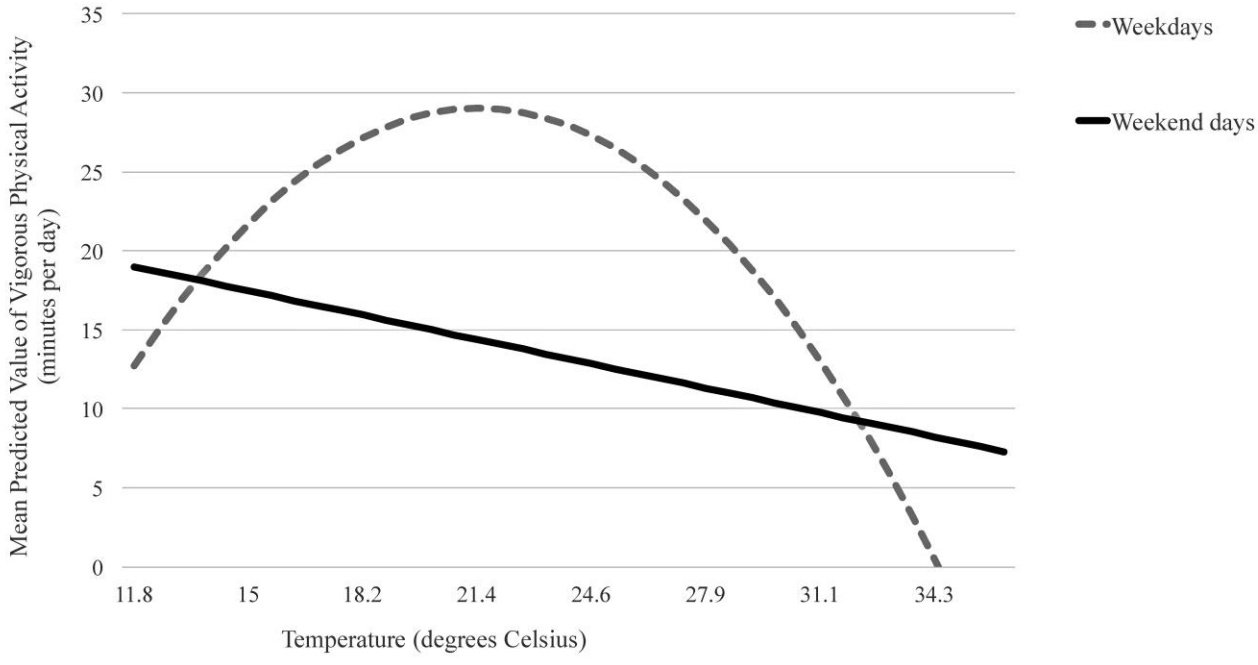
Table shows fixed effects (as standardized regression coefficients (std. B) with 95% confidence intervals (CI) from linear mixed models, with a random intercept for each child, and a repeated term for each child across each repeated observation, with autoregressive covariance structure. *: BMI was excluded from this model as its initial main effect was not statistically significant. Bolded text indicates significant at p<0.05.

Supplementary Digital Content 5: Relationship between weather elements and physical activity, and interactions between weather variables and day type (*n*=4599 days, *n*=307 children)

	Vigorous PA
	std. B (95% CI)
	-2 restricted log likelihood =
Rainfall (0.01–7.8 mm per day versus no rainfall)	0.055 (-0.001 to 0.112)
Rainfall (7.9–46.0 mm per day versus no rainfall)	-0.010 (-0.096 to 0.076)
Humidity	**-0.044 (-0.082 to -0.006)**
Day length	**-0.147 (-0.274 to -0.019)**
Temperature	**-0.625 (-1.017 to -0.233)**
Temperature squared	**0.473 (0.086 to 0.859)**
Solar Radiation exposure	**0.157 (0.109 to 0.206)**
Day type (weekday versus weekend day)	**0.343 (0.286 to 0.400)**
Gender (boys versus girls)	**0.532 (0.396 to 0.667)**
Age in years	-0.046 (-0.117 to 0.025)
Body Mass Index	**-0.102 (-0.164 to -0.041)**
Solar * Temperature	**-0.513 (-0.725 to -0.302)**
Solar * Temperature squared	**0.398 (0.188 to 0.608)**
Temperature * Day type	**0.563 (0.181 to 0.946)**
Temperature squared * Day type	**-0.626 (-0.999 to -0.254)**

Table shows fixed effects (as standardized regression coefficients (std. B) with 95% confidence intervals (CI) from linear mixed models, with a random intercept for each child, and a repeated term for each child across each repeated observation, with autoregressive covariance structure. Additional testing for 3-way interaction did not significantly improve the model. Bolded text indicates significant at $p<0.05$.

Supplementary Digital Content 6: Relationship between Temperature and Vigorous Physical Activity, moderated by day type



Mean Unstandardized Predicted Values of Vigorous Physical Activity were adjusted for rainfall, humidity, day length, solar radiation, gender, age, and BMI. In weekends, quadratic term of temperature was omitted from the model as it was no longer statistically significant in subgroup analyses. For Weekdays p-value temperature < 0.08; p-value temperature2 < 0.01. For Weekend days p-value temperature < 0.01 (temperature2 omitted from model).

Appendix 4: Supplementary material chapter 7

Table 5: Associations between playability and after-school PA, stratified for time of the day and network-distance from children's residence to school

% Light PA	Network-distance from children's residence to school			
	≤ 499 m	500–799 m	800–1199 m	≥ 1200 m
End of the school day – 16:00 h (*n* = 539)	**0.060 (0.023 to 0.097)**	0.032 (−0.007 to 0.072)	**0.071 (0.038 to 0.104)**	0.002 (−0.031 to 0.036)
16:00–18:00 h (*n* = 586)	**0.040 (0.006 to 0.075)**	−0.007 (−0.042 to 0.027)	0.027 (−0.001 to 0.055)	0.013 (−0.017 to 0.042)
18:00–20:00 h (*n* = 585)	0.026 (−0.011 to 0.063)	0.015 (−0.021 to 0.051)	0.005 (−0.024 to 0.035)	**−0.040 (−0.072 to−0.009)**
20:00–22:00 h (*n* = 326)	**0.065 (0.022 to 0.108)**	0.029 (−0.014 to 0.073)	**0.067 (0.031 to 0.104)**	**0.047 (0.010 to 0.084)**
% MVPA	Network-distance from children's residence to school			
	≤ 499 m	500–799 m	800–1199 m	≥ 1200 m
End of the school day – 16:00 h (*n* = 539)	**0.048 (0.007 to 0.090)**	**0.056 (0.009 to 0.102)**	**0.038 (0.003 to 0.073)**	−0.018 (−0.058 to 0.022)
16:00–18:00 h (*n* = 586)	**0.040 (0.003 to 0.077)**	**0.041 (0.003 to 0.079)**	0.020 (−0.008 to 0.048)	0.019 (−0.014 to 0.053)
18:00–20:00 h (*n* = 585)	**0.039 (0.001 to 0.078)**	0.023 (−0.016 to 0.062)	**−0.034 (−0.063 to−0.005)**	**−0.038 (−0.073 to−0.003)**
20:00–22:00 h (*n* = 326)	−0.005 (−0.052 to 0.041)	0.001 (−0.049 to 0.049)	0.027 (−0.010 to 0.064)	**0.044 (0.002 to 0.086)**

Standardized beta's (with 95 % confidence intervals in brackets) from linear mixed model analyses with a random intercept and slope over time (one-hour periods), nested within the dates at which measurement commenced. Results were adjusted for age, gender, average temperature, average duration of rainfall, and average duration of sunshine per

DANKWOORD

Dit proefschrift beschrijft onderzoek naar invloeden op het beweeggedrag van kinderen, en dan met name factoren in de fysieke en sociale omgeving. De omgeving heeft namelijk grote invloed op het gedrag van het individu. In dat opzicht zijn de analyses die ik de afgelopen vijf jaar heb uitgevoerd ook direct van toepassing op mijn eigen promotietraject. Mijn promotietraject is namelijk ook in grote mate positief beïnvloed door factoren in de fysieke en sociale omgeving. In dit laatste hoofdstuk zou ik graag, geheel in lijn met de hoofdstukken hiervoor, willen ingaan op de factoren in de sociale omgeving die mijn proefschrift hebben gemaakt tot wat het nu is.

Te beginnen met mijn promotieteam: Carel, Stef, Sanne en Dick. Ik had me geen beter begeleidingsteam kunnen wensen, echt waar! Op momenten dat de tijd het toeliet gaven jullie mij de vrijheid en mogelijkheden om mijn eigen weg te kiezen, maar jullie waren er daarentegen snel bij wanneer intensiever contact nodig was. Bedankt voor het uitgebreide commentaar op mijn soms wat warrig (en wollig) opgeschreven manuscripten. Zonder jullie inbreng lagen deze artikelen waarschijnlijk nog steeds te wachten om gepubliceerd en vooral goed begrepen te worden! Jullie kennis en kunde in combinatie met een flinke dosis positiviteit en humor is volgens mij het ideale vaccin tegen de onzekerheid en stress die soms komt kijken bij een promotietraject. Ik kijk met plezier uit naar het voortzetten van onze samenwerking. Carel en Stef, ontzettend bedankt voor het vertrouwen en alle kansen die jullie mij geboden hebben. Gedurende mijn stages bij het KOALA geboortecohort in 2011 en 2012 heb ik dankzij jullie het plezier in het doen van onderzoek ervaren en heb ik dat plezier nu nog steeds! De vier jaar zijn omgevlogen; jullie zijn een fantastisch duo!

Vervolgens wil ik graag Nanne, Rob, Maria, Steven en Jasper, als leden van de beoordelingscommissie van dit proefschrift, bedanken voor hun inzet tijdens het beoordelingsproces.

Ook zou ik graag de onderzoekers waar ik gedurende mijn promotietraject intensief mee heb mogen samenwerken benoemen. Ester, gedurende mijn masterstudies aan de Universiteit Maastricht heb je mij begeleid in mijn afstudeeronderzoeken. Mede dankzij jouw kundige en intensieve begeleiding zijn deze afstudeeronderzoeken gepubliceerd en dat heeft mijn prille wetenschappelijke carriere een boost gegeven! Hein, Amy, Suzanne, Remy en Carry, bedankt voor jullie begeleiding en de leuke, leerzame samenwerking in het kader van mijn tijd bij het Erasmus MC in Rotterdam. Menno, tijdens mijn afstudeerscriptie heb je mij geïnspireerd tot het doen van onderzoek. We zijn elkaar vele jaren later opnieuw tegengekomen tijdens onze samenwerking rondom het PHASE-kids

onderzoek. Daarom vind ik het bijzonder dat we nu opnieuw dagelijks samenwerken op de Fontys Sporthogeschool. Dave, jij begon in Maastricht als eerste op een project dat gebruik maakte van accelerometer- en GPS data en je hebt mij geholpen om deze techniek ook zelf te gaan gebruiken. Ik had me geen betere voorganger en tegelijkertijd fijnere kamergenoot kunnen wensen; bedankt voor een prachtige tijd! Moest het daarom gewoon zo zijn dat we elkaar op de Fontys Sporthogeschool als collega's weer tegenkwamen? Ik ben blij dat je me wilt ondersteunen als paranimf en zie uit naar een verdere samenwerking met jou in Eindhoven. Marijke, vond het erg leuk dat je mijn Utrechtse duo-promovendus was! Wat een strakke planning dat we twee dagen na elkaar ons proefschrift gaan verdedigen. Dat gezamenlijke paper gaat nog wel komen!

David, Anna, Jo, Nicky, Jenny and Lukar, thank you for the inspiring and educational visit at the Institute for Physical Activity and Nutrition in Melbourne, Australia. For me, it was very special that this relatively short visit resulted in an interesting paper that is now part of this thesis. Thank you for an unforgettable experience and hopefully we can continue our collaboration in the near future!

Daarnaast wil ik graag iedereen bedanken die in enige vorm heeft meegewerkt aan de voorbereiding, uitvoering en data-verzameling van de PHASE-kids studie. In het bijzonder natuurlijk de deelnemende scholen, ouders en kinderen. De ondersteuning van Peter Kool, Harrie van Schijndel, en alle combinatiefunctionarissen van de gemeente 's-Hertogenbosch zijn van enorm belang geweest in het verzamelen van deze prachige data. Daarnaast ben ik Tim, Marieke en Veerle erg dankbaar voor hun assistentie met het verzamelen van de gegevens en het onderhouden van contact met de scholen!

Verder wil ik alle (ex-)collega-onderzoekers van de vakgroepen Epidemiologie en Gezondheidsbevordering, evenals collega's betrokken in de ondersteuning van beide vakgroepen, van harte bedanken voor de leuke, gezellige tijd samen. Keep up the good work! Daarnaast wil ik ook graag mijn collega's van de Sporthogeschool, en dan in het bijzonder Leon, Steven, Jorrick, Joost, Anouk, Sofie, Gwen, Dianne, Lars, Dave, Menno en Matty bedanken voor jullie interesse en de mogelijkheid om de laatste loodjes van mijn proefschrift te kunnen combineren met mijn werkzaamheden in Eindhoven. Ik zie ernaar uit om straks, na afronding van mijn promotie, mezelf echt helemaal te kunnen focussen op de leuke inspirerende onderwijs- en onderzoeksactiviteiten op de Sporthogeschool!

Tot slot; beste vrienden en familie, heel erg bedankt voor jullie support en interesse de afgelopen jaren. Hopelijk heb ik straks wat meer tijd om gezellige dingen te gaan

ondernemen. In het speciaal wil ik hier mijn oud-studiegenoten en vrienden Maarten, Joep, Hein, Michiel, Vincent en Mitch noemen. Alhoewel onze humor en dialect voor buitenstaanders soms lastig te begrijpen is, geniet ik nog steeds met volle teugen van ons samenzijn en uitstapjes. Daarnaast kan de gehele familie Groscovic in dit dankwoord ook niet ontbreken. Martijn, Paul, Sjoerd, Bas en Rene, waar ook ter wereld zullen we altijd met elkaar verbonden blijven dankzij de indringende tenorstem van Jose Carreras, de brouwsels van de Abbaye Trappiste de Rochefort en onze avonturen nabij 51.751365-5.991098. Paul, ik vind het heel bijzonder en erg fijn dat jij me gaat ondersteunen als paranimf tijdens dit belangrijke moment. Daarnaast wil ik graag John, Marion, Tom, Sonja en Hidde bedanken voor hun steun en interesse gedurende mijn promotietraject.

Lieve Maartje, Maarten en Jip, ontzettend bedankt voor jullie steun, praktische hulp en gezellige momenten de afgelopen jaren. Pap en mam, jullie hebben vanaf het allereerste begin achter me gestaan. De immense betrokkenheid en onvoorwaardelijke steun van julllie is heel erg fijn. Van het verzamelen van interessante krantenknipsels tot het 'stikken' van ongeveer 200 GPS hoesjes voor deelnemende kinderen, jullie deden het allemaal met plezier. Dank jullie wel! De momenten met het inmiddels grote gezin doen mij heel erg goed.

Dan rest mij nog één persoon in het bijzonder te bedanken: mijn liefste Sanne! Bedankt voor al je liefde, steun en zorgzaamheid. Together we make a great team! Ik kijk uit naar alle mooie dingen die voor ons nog gaan komen.

Teun

CURRICULUM VITAE

Teun Remmers was born on March 1th 1988 in Rosmalen, the Netherlands. In 2009 he graduated from the Bachelor Physical Education at Fontys University of Applied Sport Sciences. Hereafter, he continued his studies at Maastricht University. He graduated from the Master of Science Physical Activity and Health: Sports and Physical Activity Interventions in 2011. In 2012 he obtained another Master of Science degree in Public Health and Epidemiology at Maastricht University.

After his studies he started working as a researcher at the Department of Public Health at Erasmus Medical Center in Rotterdam. Here he collaborated on various research projects focusing on the primary prevention of overweight and obesity in children.

In October 2013, he returned to Maastricht to work as a PhD candidate on a project studying environmental determinants of children's physical activity at the Department of Epidemiology, Maastricht University. During his PhD trajectory, he collaborated with national and international colleagues on projects involving objective measurements of physical activity behavior and he performed various teaching activities at the departments of Epidemiology and Health Promotion. In addition, he acted as peer-reviewer for several scientific international journals.

In December 2016, he started working as a lecturer and researcher at Fontys University of Applied Sport Sciences. Here he works on various projects in the field of physical education and health promotion.

PUBLICATION LIST

Publications presented in this thesis

Remmers T, Sleddens EF, Gubbels JS, De Vries SI, Mommers M, Penders J, Kremers SP, Thijs C. Relationship between physical activity and the development of body mass index in children. Medicine & Science in Sports & Exercise. 2013;46(1):177-84.

Remmers T, Sleddens EF, Kremers SP, Thijs C. Moderators of the relationship between physical activity enjoyment and physical activity in children. Journal of Physical Activity and Health. 2015;12(8):1066-73.

Remmers T, Broeren SM, Renders CM, Hirasing RA, van Grieken A, Raat H. A longitudinal study of children's outside play using family environment and perceived physical environment as predictors. International Journal of Behavioral Nutrition and Physical Activity. 2014;11(1):76.

Remmers T, Van Kann DH, Gubbels JS, Schmidt S, de Vries SI, Ettema D, Kremers SP, Thijs C. Moderators of the longitudinal relationship between the perceived physical environment and outside play in children: the KOALA birth cohort study. International Journal of Behavioral Nutrition and Physical Activity. 2014:11(1); 150.

Remmers T, Thijs C, Timperio A, Salmon J, Veitch J, Kremers SP, Ridgers ND. Daily weather and children's physical activity patterns. Medicine & Science in Sports & Exercise. 2017;49(5):922-29.

Remmers T. Van Kann DH. Thijs C. de Vries SI, Kremers SP. Playability of school-environments and after-school physical activity among 8–11 year-old children: specificity of time and place. International Journal of Behavioral Nutrition and Physical Activity. 2017;13(1):82.

Remmers T, Thijs C, Ettema D, de Vries SI, Slingerland M, Kremers SP. Critical hours and important environments: relationships between after-school physical activity and the built environment using GPS, GIS and accelerometers in 10-12-year-old children. Submitted for Publication.

Remmers T, de Vries SI, Ettema D, Kremers SP, Thijs C. Unravelling the physical activity context: investigating context-specific physical activity patterns in transition from primary to secondary school using accelerometers, GPS, and GIS. Submitted for Publication.

Other peer-reviewed international publications

Remmers T, van Grieken A, Renders CM, Hirasing RA, Broeren SM, Raat H. Correlates of parental misperception of their child's weight status: the 'be active, eat right' study. Plos One. 2014;9(2).

Raat H, Struijk MK, Remmers T, Vlasblom E, van Grieken A, Broeren SM, te Velde SJ, Beltman M, Boere-Boonekamp MM, L'Hoir MP. Primary prevention of overweight in preschool children, the BeeBOFT study (breastfeeding, breakfast daily, outside playing, few sweet drinks, less TV viewing): design of a cluster randomized controlled trial. BMC Public Health. 2013;13(1):974

This doctoral thesis presents the results from eight studies, investigating children's physical activity behaviour. The majority of these studies focussed on influences of the physical environment. Innovative technological advances (such as accelerometers, GPS measurements and Geospatial Information Systems) were used to measure attributes of the environment and to specifically determine where, when, and in which context physical activity takes place. Results showed that environmental influences differ between several contexts, and the afterschool time period was identified as an important window of opportunity. More specifically, encouraging results were found for the influence of environments with more greenspace and active transportation infrastructure (e.g. cycling and pedestrian paths) on children's afterschool physical activity.