RELATIONSHIPS AMONG PHYSICAL ACTIVITY, DIET, AND OBESITY

MEASURES DURING ADOLESCENCE

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RELATIONSHIPS AMONG PHYSICAL ACTIVITY, DIET, AND OBESITY MEASURES DURING ADOLESCENCE

A

THESIS

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Abstract

Today's high prevalence of obesity is a concern especially in youth. Physical activity and diet are both important factors associated with weight management, and current recommendations are to consume a diet low in saturated fat and high in fiber, fruit and vegetables and to participate in frequent and regular physical activity. Adherence to recommendations is low, a factor that is strongly correlated with development of obesity and associated chronic diseases such as hypertension and cardiovascular disease. While associations between diet and physical activity are well established, investigation of changes in their association during growth is lacking.

This thesis uses five years of diet, physical activity, and anthropometric data from 2379 adolescent girls in the National Heart Lung and Blood Institutes, Growth and Health Study to explore associations among diet, physical activity, and obesity cross-sectionally and with age.

Variables representing physical activity, diet quality, and obesity, as well as income, maturation stage, and other potential confounders, were evaluated pair-wise for correlation, and bivariate statistics were examined for longitudinal trends. For further evaluation of relationships between groups of variables we used a canonical correlation analysis. First, physical activity variables were grouped with confounders and examined in relationship to diet quality variables; next, we grouped physical activity, diet quality, and confounders and examined the relationship to obesity measures.

We found a moderately increasing correlation between physical activity and diet with age and an age-related decrease in correlation of all health behaviors and confounding variables with obesity measures, indicating that obesity measures become less sensitive to behaviors and socioeconomic factors with age at the same time as health behaviors become more tightly linked.

These results suggest that while health behaviors continue to interact during growth, and in fact become more intertwined, measures of obesity become more static and may be less responsive to potential interventions with increasing age. These findings should motivate intervention work to aim for youth as potential impact would be greater before health behaviors and obesity measures become "locked in" to the more static frame of adulthood.

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CHAPTER 1

Literature Review

1.1 Current Obesity Statistics and Health Recommendations

Both juvenile and adult obesity are common in the United States. According to the latest National Health and Nutrition Examination Survey (NHANES), the prevalence of juvenile obesity (body mass index [BMI] ≥ 95^{th} percentile of the BMI-for-age by Center for Disease Control normalized growth charts, 1978) is 16.9% and adult male and female obesity (BMI ≥ 30 kg/m^2) is 35.5% and 35.8% respectively (1, 2). While obesity in itself may not be a disease (3), costly chronic health conditions such as hypertension, cardiovascular disease (CVD) and type two diabetes mellitus are associated with obesity (3-6). The exact etiology of obesity and related diseases differs between both individuals and groups, but dietary and physical activity patterns are significantly correlated with obesity development (7-10). Current United States Department of Agriculture (USDA) dietary guidelines for weight management advise Americans to consume a diet low in energy density and high in micronutrient density and to balance diet with a minimum of recommended levels of physical activity (11).

1.2 Physical Activity

Physical activity recommendations are 60 minutes daily for 6-17 year olds, and 150 minutes a week of moderate or 75 minutes a week of moderate/vigorous activity for adults; however, it is noted that exceeding the physical activity recommendations provides additional and more extensive health benefits (11).

Physical activity has been historically necessary as a part of everyday living, but the necessity of physical activity for survival has declined. NHANES provides extensive continuous information about American physical activity habits (12-14), and, perhaps in conjunction with the increase in obesity over the last decades (2, 15, 16), health surveys consistently show that Americans rarely achieve physical activity recommendations (12-14). Recent NHANES accelerometer measures of physical activity, including occupational and transportation activity, show that adherence to physical activity recommendation is substantially lower than previous estimates by self-report (12-14). Current adherence to a minimum or more of recommended physical activity is 42% for 6-11 year olds, 8% for 12-19 year olds and less than 5% for adults (14).

Independent from the association with obesity development, physical activity levels affect general health (17-19). Moderating levels of blood lipids such as cholesterol and triglycerides is an important component in maintaining cardiovascular health (20, 21), and some blood lipids, including high-density-lipoprotein cholesterol and triglycerides, are directly influenced by the regularity and duration of physical activity (22, 23). In addition to cardiovascular health benefits, physical activity also increases caloric expenditure making it a recommended approach to combat weight gain (17, 24, 25). Current trends of declining physical activity are significantly correlated with the present rise in obesity and related diseases (26, 27).

1.3 Diet Quality

Diet is another key factor contributing to obesity and related diseases (28, 29). Central to existing dietary guidelines for weight management from both the USDA and American Heart Association is limiting calorie intake and increasing diet quality and micronutrient density by choosing fruits, vegetables, and foods high in fiber and low in sugar and saturated fat (11, 30). Regrettably, these guidelines are often not met by American adults or children (31, 32). Emerging as a good measure of overall diet quality is dietary energy density (ED), measured as Kcal/gram. Foods such as fruits and vegetables have a low energy density due to their high water content (33, 34), and energy density also captures foods high in calories from fat (35, 36). Additionally, in the industrialized world, high dietary energy density is associated with poor diet quality characterized by low intakes of fruits and vegetables (35, 37-39). Thus energy density represents several influential dietary aspects associated with obesity and related diseases (40, 41).

1.4 Energy Density Estimation

Research using energy density to evaluate diet quality is fairly new approach, and there is some debate regarding calculation criteria. Energy density in the diet is a basic division of kilo-calories in consumed food by gram intake, but inclusion of beverages complicates the measures. Energy density in foods depends greatly on the water content in the food as water adds weight but no calories (33, 39, 42, 43). Since beverages have high water content, they are low in energy density and their inclusion tends to yield a low estimate of dietary energy density (33, 39). However, various amounts of energy are consumed with beverages in a contemporary diet, so excluding them will underestimate dietary intake (33). Current research uses multiple energy density calculations to adjust for energy density differences in liquid and solid intake including calculations for food only, food and select beverages, and food and all beverages except water (33, 34, 44). Multiple calculations of energy density allow this measure to capture both information from food intake and additional information regarding calories from beverages. However energy density is calculated, the increasing body of research indicates that it is a good diet quality measure in diet-obesity research (33, 34, 39-42, 45-48).

1.5 Energy Density and Food Intake

In addition to being a good diet quality measure, energy density is positively correlated with energy intake and spontaneous food consumption (34, 48) and impacts obesity through interactions with energy intake independent of other dietary components (40, 45-47, 49, 50). The positive association between energy density and overall intake is to some extent due to higher palatability and calorie content of energy dense foods (34, 51, 52), but energy density affects overall intake through appetite regulating mechanisms as well (46-48, 53). A study by Stubbs et al. manipulating fat and carbohydrate content in foods indicates that intake of protein and carbohydrates is balanced in an auto-regulatory fashion to reach equilibrium with protein and carbohydrate storage in the human body. Conversely, they found that fat balance becomes positive in response to increased fat content in the food affecting a fat surplus (45). Energy dense foods tend to be high in fat, and this could explain the propensity to over-consume calories that is associated with diets high in energy density (48, 49, 53).

The oxidative hierarchy of macronutrients for energy in the body and the body's ability to store nutrients may explain the lack of intake regulation elicited by fat. Irrespective of energy density, most meals contain a mix a macronutrients and they are oxidized in the body in order of carbohydrate, protein, then fat (49). Both carbohydrates and protein are stored in limited amounts and have a precise and effective oxidative and storage feed-back mechanism. However, the human body's ability to store large amounts of fat reduces regulatory compensation for high fat intake by absence of a feedback mechanism triggered by fat intake (49, 54, 55). The high fat content in energy dense foods subsequently places them at the bottom of the metabolic oxidative hierarchy affecting overconsumption and excessive storage (49, 54).

Although macronutrients are ranked with regards to the oxidative hierarchy, they are oxidized for energy concurrently. Oxidation of nutrients in the body is measured by the respiratory quotient which measures conversion of O_2 to CO_2. Essentially the respiratory quotient is a ratio of CO_2 eliminated from the body or exhaled to O_2 consumed (45, 54). The respiratory quotient is influenced by the mixture of macronutrient being oxidized; for carbohydrates at the top of the oxidative hierarchy the respiratory quotient is 1, and for fat, which is oxidized as fatty acid, it is 0.7 (54). The respiratory quotient will range between these values depending on the mix of macronutrients. Fatty acid oxidation increases with increasing fat intake (49, 56, 57) effectively lowering the respiratory quotient in response to a high fat intake (54). Exercise also lowers the respiratory quotient by increasing fatty acid oxidation in muscles performing or adapting to physical activity (58-60). Subsequently fatty acid oxidation and the respiratory quotient are sensitive to both energy density in the diet (by association with dietary fat intake) and to physical activity.

1.6 Associations between Diet and Exercise

As both diets high in fat, and therefore in energy density, and physical activity increase fatty acid oxidation, physical activity may affect fat intake and dietary energy density through oxidative feedback mechanisms (49). Accelerated fatty acid oxidation in response to physical activity may be counteracted by selection of a diet low in fat and energy density because low fat intake suppresses fatty acid oxidation due to higher carbohydrate proportion (49, 60). Conversely, diets with low carbohydrate to fat proportion accelerates fatty acid oxidation (49), so oxidation decreases due to decreasing physical activity could be innately balanced by intake of a diet higher in fat and energy density. High fat and energy density is associated with high intake of calories (35), and caloric intake would be expected to increase in individuals who increase their physical activity level. However, the relationship between caloric intake and physical activity is not linear (59, 61-63), and physical activity decreases appetite after physical activity levels are increased (61-63) indicating complex interactions between physical activity and diet.

Not only does physical activity physiologically affect dietary response processes, it is also known to be behaviorally associated with dietary choices and other health behaviors (64-

66). Physical activity and positive health behaviors, both dietary and risk behaviors, are positively correlated (64-67). Gillman et al. found that low fruit and vegetable intake was correlated with sedentary behaviors and physical activity was related to lower saturated fat, trans fat, and cholesterol intake in a diverse cohort of 1322 men and women (65). Similarly, Pate et al. found physical activity to be significantly associated with diet choices and other health behaviors such as smoking in the 1990 Youth Risk Behavior Survey of 11631 high school students (64). Teasing apart physiological and behavioral components of physical activity and diet interactions would require extensive clinical research, but the association between the two is well established (68-70).

1.7 Changes in Patterns of Association

As both physical activity and dietary fat affect fatty acid oxidation and as interactions between diet and physical activity are recognized, an analysis exploring associations between physical activity and diet quality including dietary energy density is warranted. Patterns of association, both behavioral and physiological, continue to change over time particularly in youth and children (71-73). Furthermore, declining physical activity, low diet quality, and subsequent obesity and related diseases are becoming more prevalent in the juvenile population (2, 13, 19, 31, 74, 75). Exploring the association between diet quality and physical activity both cross-sectionally and longitudinally in a juvenile cohort could reveal possible associations as well as potential changes in associations during growth.

1.8 The National Growth and Health Study

The National Heart Lung and Blood Institute, Growth and Health Study (NGHS) was designed to examine racial differences in development of obesity and cardiovascular disease risk in adolescent girls (27, 76-78). The study research group found that both sedentary behaviors and high fat intake were correlated with obesity development and cardiovascular disease risk factors in this cohort (76, 79, 80). Moreover, a drastic decline in physical activity during adolescence correlated strongly with increases in BMI and adiposity (27, 77, 78). However, the relationship between diet quality including dietary energy density and physical activity and their potentially interactive contribution to obesity development has not been examined in this cohort. Examination of these factors could clarify potential associations during adolescence.

1.9 Research Objectives

This thesis builds on previous literature by addressing the need to understand the association between physical activity and diet quality including energy density. This work will also complement prior NGHS analyses by examining the relationship between diet quality and physical activity over time, and we furthermore aim to evaluate diet and activity for correlation with obesity status during adolescent development. This work was approved by University of Alaska Fairbanks Institutional Review Board (IRB),(IRB ID# 231373-4). The analysis objectives were approved and the data request fulfilled through the National Heart Lung and Blood Institute's Biologic Specimen and Data Repository Information Coordinating Center (BioLINCC).

Objectives

1. To explore the association between physical activity and diet quality over time in the NGHS

2. To explore diet and physical activity as correlates of juvenile obesity (BMI, percent body fat) cross-sectional and over time in the NGHS

1.10 References

1. Flegal, K.M., et al., *Prevalence of obesity and trends in the distribution of body mass index among US adults, 1999-2010.* JAMA, 2012. **307**(5): p. 491-7.

2. Ogden, C.L., et al., *Prevalence of obesity and trends in body mass index among US children and adolescents, 1999-2010.* JAMA, 2012. **307**(5): p. 483-90.

3. Hubert, H.B., et al., *Obesity as an independent risk factor for cardiovascular disease: a 26-year follow-up of participants in the Framingham Heart Study.* Circulation, 1983. **67**(5): p. 968-77.

4. Steinberger, J., et al., *Adiposity in childhood predicts obesity and insulin resistance in young adulthood.* J Pediatr, 2001. **138**(4): p. 469-73.

5. Bonadonna, R.C., et al., *Obesity and insulin resistance in humans: a dose-response study.* Metabolism, 1990. **39**(5): p. 452-9.

6. Rexrode, K.M., J.E. Manson, and C.H. Hennekens, *Obesity and cardiovascular disease.* Curr Opin Cardiol, 1996. **11**(5): p. 490-5.

7. Eisenmann, J.C., R.T. Bartee, and M.Q. Wang, *Physical activity, TV viewing, and weight in U.S. youth: 1999 Youth Risk Behavior Survey.* Obes Res, 2002. **10**(5): p. 379-85.

8. King, G.A., et al., *Relationship of leisure-time physical activity and occupational activity to the prevalence of obesity.* Int J Obes Relat Metab Disord, 2001. **25**(5): p. 606-12.

9. Bar-Or, O., et al., *Physical activity, genetic, and nutritional considerations in childhood weight management.* Med Sci Sports Exerc, 1998. **30**(1): p. 2-10.

10. Swinburn, B.A., et al., *Diet, nutrition and the prevention of excess weight gain and obesity.* Public Health Nutr, 2004. **7**(1A): p. 123-46.

11. United States Department of Agriculture, U.S.D.o.H.a.H.S., *Dietary Guidelines for Americans 2010.* 2011.

12. Hawkins, M.S., et al., *Objectively measured physical activity of USA adults by sex, age, and racial/ethnic groups: a cross-sectional study.* Int J Behav Nutr Phys Act, 2009. **6**: p. 31.

13. Pratt, M., C.A. Macera, and C. Blanton, *Levels of physical activity and inactivity in children and adults in the United States: current evidence and research issues.* Med Sci Sports Exerc, 1999. **31**(11 Suppl): p. S526-33.

14. Troiano, R.P., et al., *Physical activity in the United States measured by accelerometer.* Med Sci Sports Exerc, 2008. **40**(1): p. 181-8.

15. Flegal, K.M., et al., *Prevalence and trends in obesity among US adults, 1999-2008.* JAMA, 2010. **303**(3): p. 235-41.

16. Flegal, K.M., et al., *Overweight and obesity in the United States: prevalence and trends, 1960-1994.* International Journal of Obesity, 1998. **22**(1): p. 39-47.

17. Haskell, W.L., et al., *Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association.* Circulation, 2007. **116**(9): p. 1081-93.

18. Adams, V., et al., *Impact of regular physical activity on the NAD(P)H oxidase and angiotensin receptor system in patients with coronary artery disease.* Circulation, 2005. **111**(5): p. 555-62.

19. Andersen, L.B., et al., *Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study).* Lancet, 2006. **368**(9532): p. 299-304.

20. Liese, A.D., et al., *Association of DASH diet with cardiovascular risk factors in youth with diabetes mellitus: the SEARCH for Diabetes in Youth study.* Circulation, 2011. **123**(13): p. 1410-7.

21. Rodriguez, B.L., et al., *Prevalence of cardiovascular disease risk factors in U.S. children and adolescents with diabetes: the SEARCH for diabetes in youth study.* Diabetes Care, 2006. **29**(8): p. 1891-6.

22. Evans, R.K., et al., *Evaluation of a 6-month multi-disciplinary healthy weight management program targeting urban, overweight adolescents: effects on physical fitness, physical activity, and blood lipid profiles.* Int J Pediatr Obes, 2009. **4**(3): p. 130-3.

23. Raitakari, O.T., et al., *Effects of persistent physical activity and inactivity on coronary risk factors in children and young adults. The Cardiovascular Risk in Young Finns Study.* Am J Epidemiol, 1994. **140**(3): p. 195-205.

24. Li, S.X., et al., *Physical Activity Attenuates the Genetic Predisposition to Obesity in 20,000 Men and Women from EPIC-Norfolk Prospective Population Study.* Plos Medicine, 2010. **7**(8): p. -.

25. Simon, C., et al., *Successful overweight prevention in adolescents by increasing physical activity: a 4-year randomized controlled intervention.* Int J Obes (Lond), 2008. **32**(10): p. 1489-98.

26. Dencker, M., et al., *Daily physical activity related to body fat in children aged 8-11 years.* J Pediatr, 2006. **149**(1): p. 38-42.

27. Kimm, S.Y., et al., *Relation between the changes in physical activity and body-mass index during adolescence: a multicentre longitudinal study.* Lancet, 2005. **366**(9482): p. 301-7.

28. Bazzano, L.A., et al., *Fruit and vegetable intake and risk of cardiovascular disease in US adults: the first National Health and Nutrition Examination Survey Epidemiologic Follow-up Study.* Am J Clin Nutr, 2002. **76**(1): p. 93-9.

29. Fung, T.T., et al., *Association between dietary patterns and plasma biomarkers of obesity and cardiovascular disease risk.* Am J Clin Nutr, 2001. **73**(1): p. 61-7.

30. Lichtenstein, A.H., et al., *Diet and lifestyle recommendations revision 2006: a scientific statement from the American Heart Association Nutrition Committee.* Circulation, 2006. **114**(1): p. 82-96.

31. Troiano, R.P., et al., *Energy and fat intakes of children and adolescents in the united states: data from the national health and nutrition examination surveys.* Am J Clin Nutr, 2000. **72**(5 Suppl): p. 1343S-1353S.

32. Krebs-Smith, S.M., et al., *Americans do not meet federal dietary recommendations.* J Nutr, 2010. **140**(10): p. 1832-8.

33. Ledikwe, J.H., et al., *Dietary energy density determined by eight calculation methods in a nationally representative United States population.* J Nutr, 2005. **135**(2): p. 273-8.

34. Ello-Martin, J.A., et al., *Dietary energy density in the treatment of obesity: a year-long trial comparing 2 weight-loss diets.* Am J Clin Nutr, 2007. **85**(6): p. 1465-77.

35. Kant, A.K. and B.I. Graubard, *Energy density of diets reported by American adults: association with food group intake, nutrient intake, and body weight.* Int J Obes (Lond), 2005. **29**(8): p. 950-6.

36. Kant, A.K., *Reported consumption of low-nutrient-density foods by American children and adolescents: nutritional and health correlates, NHANES III, 1988 to 1994.* Arch Pediatr Adolesc Med, 2003. **157**(8): p. 789-96.

37. Andrieu, E., N. Darmon, and A. Drewnowski, *Low-cost diets: more energy, fewer nutrients.* Eur J Clin Nutr, 2006. **60**(3): p. 434-6.

38. Kant, A.K., *Consumption of energy-dense, nutrient-poor foods by adult Americans: nutritional and health implications. The third National Health and Nutrition Examination Survey, 1988-1994.* Am J Clin Nutr, 2000. **72**(4): p. 929-36.

39. Ledikwe, J.H., et al., *Low-energy-density diets are associated with high diet quality in adults in the United States.* J Am Diet Assoc, 2006. **106**(8): p. 1172-80.

40. Mendoza, J.A., A. Drewnowski, and D.A. Christakis, *Dietary energy density is associated with obesity and the metabolic syndrome in U.S. adults.* Diabetes Care, 2007. **30**(4): p. 974-9.

41. Mendoza, J.A., et al., *Dietary energy density is associated with selected predictors of obesity in U.S. Children.* J Nutr, 2006. **136**(5): p. 1318-22.

42. Kral, T.V., et al., *Energy density at a buffet-style lunch differs for adolescents born at high and low risk of obesity.* Eat Behav, 2009. **10**(4): p. 209-14.

43. Kral, T.V., et al., *Daily food intake in relation to dietary energy density in the free-living environment: a prospective analysis of children born at different risk of obesity.* Am J Clin Nutr, 2007. **86**(1): p. 41-7.

44. Kral, T.V., et al., *Dietary energy density increases during early childhood irrespective of familial predisposition to obesity: results from a prospective cohort study.* Int J Obes (Lond), 2007. **31**(7): p. 1061-7.

45. Stubbs, R.J., et al., *Covert manipulation of dietary fat and energy density: effect on substrate flux and food intake in men eating ad libitum.* Am J Clin Nutr, 1995. **62**(2): p. 316-29.

46. Prentice, A.M. and S.D. Poppitt, *Importance of energy density and macronutrients in the regulation of energy intake.* Int J Obes Relat Metab Disord, 1996. **20 Suppl 2**: p. S18-23.

47. Poppitt, S.D. and A.M. Prentice, *Energy density and its role in the control of food intake: evidence from metabolic and community studies.* Appetite, 1996. **26**(2): p. 153-74.

48. Duncan, K.H., J.A. Bacon, and R.L. Weinsier, *The effects of high and low energy density diets on satiety, energy intake, and eating time of obese and nonobese subjects.* Am J Clin Nutr, 1983. **37**(5): p. 763-7.

49. Prentice, A.M., *Manipulation of dietary fat and energy density and subsequent effects on substrate flux and food intake.* Am J Clin Nutr, 1998. **67**(3 Suppl): p. 535S-541S.

50. Bell, E.A. and B.J. Rolls, *Energy density of foods affects energy intake across multiple levels of fat content in lean and obese women.* Am J Clin Nutr, 2001. **73**(6): p. 1010-8.

51. Prentice, A.M. and S.A. Jebb, *Fast foods, energy density and obesity: a possible mechanistic link.* Obes Rev, 2003. **4**(4): p. 187-94.

52. McCrory, M.A., et al., *A twin study of the effects of energy density and palatability on energy intake of individual foods.* Physiol Behav, 2006. **87**(3): p. 451-9.

53. Stubbs, R.J., et al., *Covert manipulation of the ratio of dietary fat to carbohydrate and energy density: effect on food intake and energy balance in free-living men eating ad libitum.* Am J Clin Nutr, 1995. **62**(2): p. 330-7.

54. Flatt, J.P., *Carbohydrate-fat interactions and obesity examined by a two-compartment computer model.* Obes Res, 2004. **12**(12): p. 2013-22.

55. Lissner, L., et al., *Dietary fat and the regulation of energy intake in human subjects.* Am J Clin Nutr, 1987. **46**(6): p. 886-92.

56. Rolls, B.J., *Carbohydrates, fats, and satiety.* Am J Clin Nutr, 1995. **61**(4 Suppl): p. 960S-967S.

57. Tremblay, A., et al., *Impact of dietary fat content and fat oxidation on energy intake in humans.* Am J Clin Nutr, 1989. **49**(5): p. 799-805.

58. Holloszy, J.O. and E.F. Coyle, *Adaptations of skeletal muscle to endurance exercise and their metabolic consequences.* J Appl Physiol, 1984. **56**(4): p. 831-8.

59. Starritt, E.C., D. Angus, and M. Hargreaves, *Effect of short-term training on mitochondrial ATP production rate in human skeletal muscle.* J Appl Physiol, 1999. **86**(2): p. 450-4.

60. Smith, S.R., et al., *Concurrent physical activity increases fat oxidation during the shift to a high-fat diet.* Am J Clin Nutr, 2000. **72**(1): p. 131-8.

61. King, N.A., *What processes are involved in the appetite response to moderate increases in exercise-induced energy expenditure?* Proc Nutr Soc, 1999. **58**(1): p. 107-13.

62. King, N.A., et al., *High dose exercise does not increase hunger or energy intake in free living males.* Eur J Clin Nutr, 1997. **51**(7): p. 478-83.

63. King, N.A., V.J. Burley, and J.E. Blundell, *Exercise-induced suppression of appetite: effects on food intake and implications for energy balance.* Eur J Clin Nutr, 1994. **48**(10): p. 715-24.

64. Pate, R.R., et al., *Associations between physical activity and other health behaviors in a representative sample of US adolescents.* Am J Public Health, 1996. **86**(11): p. 1577-81.

65. Gillman, M.W., et al., *Relationships of physical activity with dietary behaviors among adults.* Prev Med, 2001. **32**(3): p. 295-301.

66. Berrigan, D., et al., *Patterns of health behavior in U.S. adults.* Prev Med, 2003. **36**(5): p. 615-23.

67. Simoes, E.J., et al., *The association between leisure-time physical activity and dietary fat in American adults.* Am J Public Health, 1995. **85**(2): p. 240-4.

68. Liang, W., et al., *A population-based study of age and gender differences in patterns of health-related behaviors.* Am J Prev Med, 1999. **17**(1): p. 8-17.

69. Reedy, J., P.S. Haines, and M.K. Campbell, *The influence of health behavior clusters on dietary change.* Prev Med, 2005. **41**(1): p. 268-75.

70. Patterson, R.E., P.S. Haines, and B.M. Popkin, *Health lifestyle patterns of U.S. adults.* Prev Med, 1994. **23**(4): p. 453-60.

71. Lytle, L.A., et al., *How do children's eating patterns and food choices change over time? Results from a cohort study.* Am J Health Promot, 2000. **14**(4): p. 222-8.

72. Anderssen, N., et al., *Change and secular trends in physical activity patterns in young adults: a seven-year longitudinal follow-up in the Coronary Artery Risk Development in Young Adults Study (CARDIA).* Am J Epidemiol, 1996. **143**(4): p. 351-62.

73. Malina, R.M., *Tracking of physical activity and physical fitness across the lifespan.* Res Q Exerc Sport, 1996. **67**(3 Suppl): p. S48-57.

74. Gordon-Larsen, P., M.C. Nelson, and B.M. Popkin, *Longitudinal physical activity and sedentary behavior trends: adolescence to adulthood.* Am J Prev Med, 2004. **27**(4): p. 277-83.

75. Ogden, C.L., M.D. Carroll, and K.M. Flegal, *High body mass index for age among US children and adolescents, 2003-2006.* JAMA, 2008. **299**(20): p. 2401-5.

76. Obarzanek, E., et al., *Energy intake and physical activity in relation to indexes of body fat: the National Heart, Lung, and Blood Institute Growth and Health Study.* Am J Clin Nutr, 1994. **60**(1): p. 15-22.

77. Kimm, S.Y., et al., *Decline in physical activity in black girls and white girls during adolescence.* N Engl J Med, 2002. **347**(10): p. 709-15.

78. Kimm, S.Y., et al., *Longitudinal changes in physical activity in a biracial cohort during adolescence.* Med Sci Sports Exerc, 2000. **32**(8): p. 1445-54.

79. Ritchie, L.D., et al., *Dietary patterns in adolescence are related to adiposity in young adulthood in black and white females.* J Nutr, 2007. **137**(2): p. 399-406.

80. Simon, J.A., et al., *Correlates of high-density lipoprotein cholesterol in Black girls and White girls: the NHLBI Growth and Health Study.* Am J Public Health, 1995. **85**(12): p. 1698-702.

CHAPTER 2

Physical activity and diet correlations increase during adolescence concurrent with declining association between health behaviors and obesity *

2.1 Abstract

Background: Obesity in youth is highly prevalent. Physical activity and diet are both influential in obesity development, and associations between physical activity and diet are well reported. However, there is a gap in knowledge regarding potential links between levels of physical activity and diet quality and their combined influence on obesity during adolescence.

Objectives: We use five years of anthropometric, diet, and physical activity data from 2379 adolescent girls in the National Heart Lung and Blood Institute Growth and Health Study to evaluate the association between physical activity and diet quality during adolescence and to assess both as cross-sectional and longitudinal correlates of obesity.

Design: Measures of physical activity, diet quality, BMI, body fat percent, and confounding variables such as income, were evaluated pair-wise for correlation. A canonical correlation analysis facilitated evaluation of relationships within and between groups of variables as it uses variable grouping. Physical activity was grouped with confounders to examine the relationship to diet quality. Physical activity, diet quality, and confounders were then grouped to assess their relationship to BMI and body fat percent. All statistics were examined for trends over time.

Results: There was a positive correlation between physical activity and diet quality that became stronger with age. Additionally, there was an age-related decline in the strength of correlation between obesity and several diet, physical activity, and confounding variables.

Conclusion: These results suggest that while health behaviors, including diet and physical activity, become more closely linked during growth, obesity becomes less influenced by health behaviors and socioeconomic factors. This should motivate policy and intervention workers to increase focus of obesity prevention on children capitalizing on the still pliable framework for establishing healthy diet and physical activity patterns while impact on body composition is greatest.

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2.2 Introduction

A major concern associated with the high prevalence of obesity in the United States today is the high costs of to the condition. Obesity has a high cost due to lost job performance and increased spending on health care, and there is a personal cost of reduced quality of life associated with co-morbidities (1). Type 2 diabetes mellitus, cardio vascular disease (CVD), and hypertension are examples of costly chronic conditions caused or exacerbated by obesity (2, 3), and costs associated with obesity related diseases as well as obesity prevalence increased significantly in the last part of the previous century (1).

According to the latest National Health and Nutrition Examination Survey (NHANES), United States juvenile obesity (BMI ≥ 95th percentile of the BMI-for-age using 1978 growth charts) is at 16.9%, and prevalence of adult male and female obesity (BMI ≥ 30 kg/m^2) are 35.5% and 35.8% respectively (4, 5). While the high adult obesity prevalence is daunting, more concerning is the prevalence of obesity in youth because juvenile obesity tracks into adulthood and is a precursor for obesity related chronic diseases (6).

2.2.1 Physical Activity

Adequate physical activity is an important aspect of weight management and general health in both children and adults (7). Physical activity aids weight management by increasing caloric expenditure and fatty acid oxidation (8). Current USDA dietary guidelines for weight management advise Americans to eat a varied diet and maintain a minimum of recommended levels of physical activity (9). Physical activity recommendations for ages 6-17 are 60 minutes daily, and for adults 150 minutes a week of moderate or 75 minutes a week of moderate/vigorous activity (9). Accelerometer measures of physical activity, including occupational and transportation activity, from 2003-2004 NHANES data show that adherence to physical activity recommendation is 42% for 6-11 year olds, 8% for 12-19 year olds and less than 5% for adults (10).The sub-optimal adherence to recommended physical activity levels, and the drastic decreases in physical activity during adolescence (10), particularly in girls (11), is directly correlated with the current rise in obesity (7, 8, 12).

2.2.2 Diet Quality

While low physical activity is the primary driver of rising obesity in children (13), diet is another factor related to obesity development (9, 14). Existing dietary guidelines for weight management from both USDA and American Heart Association recommend limiting calorie intake and increasing diet quality by choosing fruits, vegetables, and foods high in fiber and low in sugar and saturated fat (9, 15). Saturated fat and fiber intake are good indicators of diet quality because of the foods they are associated with; saturated fat tends to be associated with processed high fat foods, and fiber is associated with whole grain intake (15).

Dietary energy density is another good measure of overall diet quality. Energy density in the diet is measured as amount of energy per gram food (Kcal/gram), so it captures foods dense in calories regardless of the calorie source (16). Moreover, energy density can capture intake of fruits and vegetables because these foods have high water contents and water adds weight but no calories to the calculation (17). Diet quality and micro-nutrient intake, especially from fruits and vegetables, are furthermore negatively correlated with dietary energy density in the industrialized world today (16, 18). Energy density consequently represents several influential aspects of diet quality associated with obesity and related diseases (14, 16).

Dietary intake may be shifting as a consequence of high obesity prevalence because energy, fat, and saturated fat intakes have mostly declined during the last decades of the 20th century according to NHANES data. However, the majority of adults and children still exceed recommendations for both total and saturated fat intake (13, 19), and adolescent girls are singled out as the only group in NHANES analysis for whom energy intake has increased over this period (13).

2.2.3 Physical Activity and Diet Interactions

Both physical activity and diet are health behaviors that factor into obesity development, and they impact each other as well (20-22). Physical activity may decrease appetite as a short term response to increased activity levels (21), and it is also known to be positively associated with healthy dietary choices and other health behaviors (20, 22). Teasing apart the physiological and behavioral components of physical activity and diet is challenging, but the existing association is well established (20-23).

While associations between physical activity and diet are well reported in adults and youths (20, 22), less is known about whether and how the association between activity and diet quality indicators, such as energy density, saturated fat, and fiber intake, change during adolescence. Diet and activity patterns change during adolescence (24) , so it would be pertinent to examine potential changes and trends in associations between diet and physical activity behaviors and their relationship to obesity development during this time.

Reported here are results from a secondary analysis exploring associations between diet and physical activity behaviors using five years of data spanning seven years of development from adolescent girls in The National Heart Lung and Blood Institute Growth and Health Study (NGHS). We also investigated both diet and physical activity as correlates of BMI and body composition during growth. Understanding the interactions and underpinnings of diet and physical activity is paramount to stemming the obesity epidemic, and identifying changes or trends in associations during development may pinpoint the optimal intervention window for preventing adult obesity.

2.3 Subjects and Methods

2.3.1 The Growth and Health Study

The National Heart Lung and Blood Institute Growth and Health Study was conducted to evaluate racial differences in the development of obesity and CVD risk in girls. The study group recruited 1213 black girls and 1166 white girls from schools and clinics in the study areas, Berkeley, CA, Cincinnati, OH, and Rockville, MD, from January 1987 to May 1988 (25). To be eligible for the study, the girls had to be white or black with no other mixed heritage. The girls were all 9 - 10 years old at recruitment (visit 1), and attended annual visits for 10 years with a follow up rate of 89% (26). The centers collected annual blood lipid data, anthropometric measures (e.g. height, weight, skin fold thicknesses, maturation stage indicators), and dietary and physical activity questionnaires. Extensive sampling design and study methods are described elsewhere (25, 27). Analysis to assess associations between diet and exercise and to identify correlates of obesity over time in this cohort was approved by University of Alaska Institutional Review Board (ID# 231373-4). Subsequently, the analysis objectives were approved and the data request fulfilled through the National Heart Lung and Blood Institute's Biologic Specimen and Data Repository Information Coordinating Center (BioLINCC).

2.3.2 Physical Activity and Diet Measures

In the NGHS, information about physical activity levels was collected using two questionnaires- a habitual activity questionnaire (HAQ), and an activity diary (AD) (25, 27). The HAQ asked participants to report type and frequency of in school and outside school activities throughout the year. The HAQ was interviewer administered in visit years 1, 3, and 5, and it was self-administered year 7-10. The weekly scores were calculated by multiplying the weekly frequency of the activity by the fraction of year that the activity was engaged by the metabolic equivalent of task (MET) value for the activity. Weekly MET scores for reported activities for the previous year were added to yield the annual HAQ score as an estimate of physical activity throughout the year (27). In visit years 1-5, 7, 8, and 10, the participant completed an AD on three consecutive days along with a 3-day food journal. The participants were instructed to record both active (e.g., jogging, kickball, jumping rope) and sedentary (e.g., sitting to talk, watch TV, or read) behaviors listed in their AD which included designated timeslots. Along with the listed activity categories there was a blank "Other activities" section to document activities not listed in the questionnaire and space for recording the times of going to bed and waking up. Daily AD scores were calculated by multiplying the MET value for each activity by its duration and summing the calculated MET scores for all the activities in one day. Final AD score was the average of the scores for all the usable days. The participant reviewed the AD and HAQ with staff at the centers using a common protocol for submission in each collection year (27).

Information about nutrient and calorie intake was collected with the 3-day food journal each year (25, 27). The journals were completed by the participants on two consecutive weekdays and one weekend day, and the journal entries were reviewed and confirmed with staff following standardized protocol for all collection centers. Food journals were coded centrally, and processed to yield information about average kilocalorie (kcal) intake, macronutrient distribution, and average intake of 50 different nutrients. During years 1 and 2 the data were processed at the Nutrition Coordinating Center in Minnesota, and the records from the subsequent years (3-10) were processed at the NGHS Dietary Data Entry Center in Cincinnati (28).

Height, weight, and skin-fold measures were collected at annual visits (25). The average of two measures was taken, and if the two measures deviated from each other excessively (more than 0.5 cm for height, 0.3 kg for weight, and 1.0 mm for skin-folds), a third measure was included (25). Maturation was assessed with a modified Tanner staging method to accurately assess maturation at different body compositions (25).

2.3.3 Analysis

We used data from years 3, 5, 7, 8, and 10 because these years had physical activity information collected by both HAQ and AD ensuring a comprehensive physical activity assessment. We started at year three because data from this and subsequent years were processed at the Cincinnati Dietary Data Entry Center. These data include both total kcal and grams of intake which are needed for the energy density calculations. Daily energy density for each journal period was calculated by dividing the total daily kcal by the daily sum of gram intake of all reported foods and drinks including water; energy density was then averaged for all valid journal days. Our diet quality indicators were average energy density, average kcal intake, average dietary saturated fat percent, and average (gram) fiber intake. Our obesity indicators included BMI calculated from height and weight measurements and body fat percent estimated from skin fold measurements; in the NGHS body fat percent was calculated with a standard equation using measurements of triceps, subscapular, and suprailiac skin folds (25). Income, maturation stage, height, weight, race, and smoking status were included to adjust for confounding effects. To account for racial differences in the recording of physical activity measures, we included variables for racial interaction with HAQ (race x HAQ) and racial interaction with AD (race x AD) in the analyses. All statistical analyses were conducted with SPSS 22 (29).

Initially we ran bivariate correlation analyses between all pairs of variables. To account for simultaneous evaluation of multiple variables we only considered $P < 0.001$ as significant. We used Spearman's rho correlation because it is less sensitive to potential outliers than Pearson's r.

To examine the relationships between variable groups, we conducted a Canonical Correlation Analysis (CCA). Canonical correlation is a multivariate analysis where a program constructs linear combinations of two sets of variables.

Canonical variates (X): $a_1 X_{i1} + a_2 X_{i2} + \ldots + a_p X_{ip} = U_i$

Canonical covariates (Y): $b_1 Y_{i1} + b_2 Y_{i2} + \ldots + b_q Y_{iq} = V_i$

The linear indices are adjusted so that, for the i^{th} set of observations, the correlation between the two resulting latent values, U and V, is maximized. The latent values represent underlying structure in the data. Statistics from CCA include several index sets, and the first set of indices explains the largest proportion of variance in the data and has the highest canonical correlation between variates and covariates. The canonical variates are evaluated for significance in the analysis with univariate F tests. Data from CCA can be interpreted by the canonical correlation (value 0-1), a measure of correlation between the latent values from the two linear indices. Additionally, the individual coefficients in each index tell us how the variables are related to each other within the group when the groups are most correlated with each other.

To evaluate the association between physical activity and diet quality we grouped variables for CCA as follows. Canonical variates (physical activity and confounders) were income, race, height, weight, maturation stage, smoking status, race x HAQ, race x AD, HAQ, and AD, and canonical covariates (diet quality indicators) were average energy density, average kcal, average dietary saturated fat percent, and average fiber intake.

Using CCA to evaluate correlates of obesity during growth was done by grouping the variables by income, race, maturation stage, smoking, race x HAQ, race x AD, HAQ, AD, average energy density, average kcal, average dietary saturated fat percent, and average fiber intake (obesity correlates) as canonical variates and BMI and body fat percent (body composition) as canonical covariates; height and weight were not included as variates in the second part of the analysis as they define BMI and including them gave an artificially high correlation. The confounding variables were grouped with the variates in this analysis to allow evaluation of significance of these in correlation with the group of covariates. Smoking status was omitted from the final report as it was not a significant factor for correlation with diet or obesity in year three, and smoking status from the subsequent years was not available.

2.4 Results

2.4.1 Associations between Physical Activity and Diet

Figure 1 a shows that the strength of the negative correlation, as indicated by Spearman's rho, between HAQ scores and dietary energy density and between HAQ scores and dietary saturated fat percent increased with age. The increase followed a linear trend with R^2 = 0.89 for energy density and R^2 = 0.95 saturated fat percent. **Figure 1 b** shows the strength of the positive correlation, as indicated by Spearman's rho, between HAQ and fiber intake also increased with age ($R^2 = 0.82$).

Examining association between physical activity and diet with CCA initially produced opposite coefficients for the two physical activity measures. Spearman's rho correlations between HAQ scores and 3d AD scores were positive at each visit year (coefficients 0.26, 0.29, 0.25, 0.22, and 0.10; $P < 0.001$), but HAQ scores had a positive coefficient and 3d AD scores a negative coefficient for all years in the initial CCA results. Data stratification by race revealed racial differences in physical activity questionnaire responses, so racial interaction variables were added as confounders in the CCA. **Table 1** presents standardized canonical correlation coefficients from the first index in the CCA examining association between physical activity and diet including the racial interaction variables with the confounders. The first set of indices explained 66 % to 75 % of the variance in the data. Maturation stage was included as a confounding variable in the analysis, but because these coefficients were mostly not significant, they were not reported in table 1. In visit years 3 and 5 HAQ scores and saturated fat percent had negative and positive coefficients respectively, and positive and negative coefficients respectively for years 7-10. Correlation coefficients for visits 7, 8, and 10 indicate that higher income, being white (coded as 1), and higher physical activity scores yield the highest canonical correlation to lower dietary energy density, kcal intake, and dietary saturated fat percent and higher intake of fiber.

As illustrated in **Figure 2**, the canonical correlation of physical activity and confounding variables with diet quality indicators increases with time both for the combined data, as well as for white girls. The correlation increase in Figure 2 follows a linear trend with $R^2 = 0.95$ for the combined data and $R^2 = 0.92$ for white girls. The canonical correlation for black girls does not mimic the trend for the combined date or for white girls. The correlation of physical activity and confounders with diet quality in black girls increases from year 3 to 5 but shows a sharp decrease year 7 which was the year the HAQ went from interview to self-administered indicating a potential reporting bias. From year 8 to 10 there is a weak increase in correlation for association of physical activity and confounders with diet quality in black girls indicating adherence to the general trend after adjusting to the change in recording methods.

2.4.2 Correlates of Obesity during Growth

In bivariate analysis, income, HAQ scores, and fiber intake are negatively correlated with BMI and body fat percent (Spearman's rho correlation coefficients vary from -0.06 to -0.17), and race was positively correlated with both obesity measures (Spearman's rho correlation coefficients vary from 0.09 to 0.21) in every year ($P < 0.001$) indicating that being black (black = 2, white = 1) was correlated with higher BMI and body fat percent. The correlation for BMI and body fat percent with income, race, and HAQ scores increases during the study years (increase range 0.019 to 0.129), but the correlation of BMI and body fat percent with AD scores and other diet quality variables did not increase and the sign, strength, and significance of the coefficients varied from year to year.

We conducted CCA between body composition (BMI and body fat percent) and obesity correlates (physical activity, diet quality indicators, and confounders) to investigate association within and between the groups of variables while adjusting for confounding effects. **Table 2** provides the standardized canonical correlation coefficients from the first index for canonical correlation between obesity correlates and body composition from this CCA. BMI is a measure of body fatness, but there are inverse coefficients for BMI and body fat percent. This is an effect of multicollinearity as the two correlated variables are simultaneously explaining variance in the obesity correlates. Correlation coefficients indicate that higher income and lower race score (white) consistently yielded the highest canonical correlation with body composition; however, the relationships between the other canonical variates in this portion of the analysis varied by year. For example in year 5

[0.38(Inc) – 0.32(Race) + 0.01(Rx HAQ) – 0.45 (Rx 3d AD) + 0.06(HAQ) + 0.18 (3d AD) + 0.16 (ED) + 0.30 (kcal) – 0.12 (Sat fat %) – 0.26 (fiber) = U

and -1.61(BMI) + 0.75(BF%) = V when U and V are most correlated, but in year 7

0.32(Inc) – 0.71(Race) + 0.24(Rx HAQ) + 0.14 (Rx 3d AD) – 0.04(HAQ) – 0.22 (3d AD) + 0.18 (ED) – 0.02 (kcal) + 0.28 (Sat fat %) + 0.26 (fiber) = U

and -1.19(BMI) + 0.22(BF%) = V when U and V are most correlated]

Nevertheless, some variables remained significant regardless of change in sign (positive and negative) of the coefficients. In addition to the confounders (income, race, and racial interaction variables), both activity measures and fiber intake were significant variables for canonical correlation with obesity measures for most (3d AD) or all (HAQ, fiber) visit years in the analysis. Other diet quality variables except energy density were significant for at least three of the five study years. The first set of indices explained 62 % to 84 % of the variance in the data (Table 2).

While the relationships between variables within the groups varied from year to year, the canonical correlation between the groups (obesity correlates and body composition) decreased with each subsequent visit as shown in **Figure 3**; this indicates an age-related reduction in association between obesity correlates and body composition in spite of an age-related increase in correlation for some of the variables in the bivariate results. The decreases in correlation followed linear trends with $R^2 = 0.72$ for the combined data, $R^2 = 0.93$ for black girls and $R^2 = 0.75$ for white girls.

2.5 Discussion

In this study, higher levels of physical activity were positively associated with diet quality as early as 12 years of age (visit year 3, Figures 1 and 2, Table 1). Furthermore, the correlation between diet quality and physical activity became stronger with age (Figures 1 and 2). White race and higher income, habitual activity, and fiber intake were associated with a lower BMI and body fat percent. The consistent relationship of race and income with canonical correlation to obesity in the CCA (Table 2) further supports that socioeconomic factors are a major consideration in obesity development which has been previously reported (25). The decline in canonical correlation between obesity correlates and body composition with age (Figure 3) demonstrates a decreased connection of BMI and body fat percent with both health behaviors and socioeconomic factors during transition into adulthood.

2.5.1 Physical Activity and Diet Interactions

The decreasing association between body composition and correlates of obesity during adolescence is contrasted by the increasingly tight relationship between physical activity and select indicators of diet quality with age. Similar to our findings of associations between diet quality indicators and physical activity, Gillman et al. (22) found that low fruit and vegetable intake was correlated with sedentary behaviors and more physical activity was related to lower saturated fat, trans fat, and cholesterol intake in a diverse cohort of 1322 men and women. Pate et al. (20) also found physical activity to be positively associated with diet choices as well as with other health behaviors such as choosing to smoke in the 1990 Youth Risk Behavior Survey of 11631 high school students suggesting that health behaviors have strong associations as early as high school. Our findings support earlier associations between behaviors and demonstrate an association increase with time as well. The tighter correlation between health behaviors with age indicates that more or less healthy patterns emerge with increasing cognitive maturation.

While preference shapes health behaviors, and decisions cluster with regards to diet and physical activity, physiological mechanisms such as fatty acid oxidation may also influence the association between the two because it responds to both dietary fat intake and physical activity (23). Fatty acid oxidation increases with increasing fat intake (30-32), and exercise increases fatty acid oxidation in muscle tissue performing or adapting to physical activity as well (23, 33). As high fat intake and physical activity have a similar physiological impact, accelerated fatty acid oxidation in response to physical activity may be reflexively counteracted by selection of a diet with low fat and energy density; low dietary fat intake suppresses fatty acid oxidation because it is generally higher in carbohydrate proportion (23, 32). Conversely, decreasing physical activity decreases fatty acid oxidation (34). As higher fat proportion in dietary intake accelerates fatty acid oxidation (32), oxidation decrease by decreasing physical activity level could be innately balanced by intake of a diet higher in fat and energy density. We found an increasing negative correlation between physical activity and dietary fat measures (energy density and dietary saturated fat percent) over time while physical activity declines. This increase in negative correlation falls in line with potential physiological associations between these health behaviors as well as with the existing support for health behavior patterns.

2.5.2 Obesity during Growth

Along with increasing association between health behaviors, the decrease in canonical correlation between obesity correlates and body composition indicate a potential for higher impact of behaviors on anthropometrics at younger ages. The finding that the correlation between physical activity and diet quality, two important health behaviors, and obesity gets weaker as girls age, is supported by a study demonstrating that various fat deposits are genetically distinct "mini-organs", and like other tissues they are subject to developmental processes and potential maturation (35). Similarly, a four year study of adipose tissue growth in 288 children ages 4 months to 19 years at enrollment, found fat tissue development in children potentially played a role in developing enlarged fat depots in obese adults (36). The decrease in canonical correlation between obesity correlates and body composition with age could be reflective of fat storage capacity maturing during adolescence.

In addition to, or as a consequence of, developmental effects on fat tissue, juvenile obesity increases adult obesity risk. A 35 year longitudinal British study ending in 2000 demonstrated that early weight gain predicted adult obesity (37), and a 1976 study found a 2.4 odds ratio for adult obesity associated with juvenile obesity and overweight (38). The alarming increase in obesity in the juvenile population today consequently bodes ill for obesity and subsequent health odds for the generation to come (4, 7, 13, 39). These bleak odds, in conjunction with our findings, stress the importance of attention to health habits in children when the framework of health behaviors is less settled and body composition is more responsive.

2.5.3 Limitations

Limitations of this analysis include self-report of physical activity which tends to over-estimates actual activity levels particularly at lower levels of activity, thus reducing the power to detect differences (10). The fluctuation in correlation between diet quality and physical activity (Figure 1 and 2), and between obesity correlates and body composition at year seven and eight (Figure 3) may be an artifact of the change in the questionnaire collection protocol at year seven (27).

Another limitation of this study is the inclusion of all beverages including water in the energy density calculation. Energy density depends greatly on the water content in the food (17, 18, 40), so current research uses multiple calculations to adjust for energy density differences in liquid and solid intake including calculations for food only, and food and select or all beverages except water (17, 41, 42).

The effect of these limitations is an underestimation of dietary energy density and differences in activity, and a potential underestimation of correlations and trends in the analysis. Data from an electronic physical activity monitor and dietary assessment coded for removal of beverages for multiple energy density calculations would better identify the extent of these associations. Longitudinal data from a broader age group could additionally determine if the correlation between health behaviors and between body composition and correlates of obesity continue to change with age guiding obesity prevention in the general population.

2.5.4 Conclusion

Our study not only confirmed positive associations between physical activity and diet quality in adolescent girls, we also documented an increasingly tight correlation between these two health behaviors with age. This indicates that cognitive maturation increasingly affects development of health behavior patterns during growth. As a consequence, successful interventions to increase activity during adolescence may have positive effects on diet quality as behavior patterns are established. While physical activity and diet become more tightly correlated with time, body composition becomes less associated with known obesity correlates indicating a potential maturation of fat tissues during growth. The fat tissue maturation and increasing rigidity of behavior patterns with age should spur public policy makers and intervention organizers to increase focus on promoting healthy diet and physical activity behaviors continuously through adolescence when the potential for long term impact on future health is greatest.

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2.7 References:

1. Wolf, A.M. and G.A. Colditz, *Current estimates of the economic cost of obesity in the United States.* Obes Res, 1998. **6**(2): p. 97-106.

2. Hubert, H.B., et al., *Obesity as an independent risk factor for cardiovascular disease: a 26-year follow-up of participants in the Framingham Heart Study.* Circulation, 1983. **67**(5): p. 968-77.

3. Bonadonna, R.C., et al., *Obesity and insulin resistance in humans: a dose-response study.* Metabolism, 1990. **39**(5): p. 452-9.

4. Ogden, C.L., et al., *Prevalence of obesity and trends in body mass index among US children and adolescents, 1999-2010.* JAMA, 2012. **307**(5): p. 483-90.

5. Flegal, K.M., et al., *Prevalence and trends in obesity among US adults, 1999-2008.* JAMA, 2010. **303**(3): p. 235-41.

6. Guo, S.S. and W.C. Chumlea, *Tracking of body mass index in children in relation to overweight in adulthood.* Am J Clin Nutr, 1999. **70**(1 Part 2): p. 145S-148S.

7. Andersen, L.B., et al., *Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study).* Lancet, 2006. **368**(9532): p. 299-304.

8. Simon, C., et al., *Successful overweight prevention in adolescents by increasing physical activity: a 4-year randomized controlled intervention.* Int J Obes (Lond), 2008. **32**(10): p. 1489-98.

9. United States Department of Agriculture, U.S.D.o.H.a.H.S., *Dietary Guidelines for Americans 2010.* 2011.

10. Troiano, R.P., et al., *Physical activity in the United States measured by accelerometer.* Med Sci Sports Exerc, 2008. **40**(1): p. 181-8.

11. Andersen, R.E., et al., *Relationship of physical activity and television watching with body weight and level of fatness among children: results from the Third National Health and Nutrition Examination Survey.* JAMA, 1998. **279**(12): p. 938-42.

12. Berkey, C.S., et al., *One-year changes in activity and in inactivity among 10- to 15-year-old boys and girls: relationship to change in body mass index.* Pediatrics, 2003. **111**(4 Pt 1): p. 836-43.

13. Troiano, R.P., et al., *Energy and fat intakes of children and adolescents in the united states: data from the national health and nutrition examination surveys.* Am J Clin Nutr, 2000. **72**(5 Suppl): p. 1343S-1353S.

14. Bazzano, L.A., et al., *Fruit and vegetable intake and risk of cardiovascular disease in US adults: the first National Health and Nutrition Examination Survey Epidemiologic Follow-up Study.* Am J Clin Nutr, 2002. **76**(1): p. 93-9.

15. Lichtenstein, A.H., et al., *Diet and lifestyle recommendations revision 2006: a scientific statement from the American Heart Association Nutrition Committee.* Circulation, 2006. **114**(1): p. 82-96.

16. Kant, A.K. and B.I. Graubard, *Energy density of diets reported by American adults: association with food group intake, nutrient intake, and body weight.* Int J Obes (Lond), 2005. **29**(8): p. 950-6.

17. Ledikwe, J.H., et al., *Dietary energy density determined by eight calculation methods in a nationally representative United States population.* J Nutr, 2005. **135**(2): p. 273-8.

18. Ledikwe, J.H., et al., *Low-energy-density diets are associated with high diet quality in adults in the United States.* J Am Diet Assoc, 2006. **106**(8): p. 1172-80.

19. Krebs-Smith, S.M., et al., *Americans do not meet federal dietary recommendations.* J Nutr, 2010. **140**(10): p. 1832-8.

20. Pate, R.R., et al., *Associations between physical activity and other health behaviors in a representative sample of US adolescents.* Am J Public Health, 1996. **86**(11): p. 1577-81.

21. King, N.A., V.J. Burley, and J.E. Blundell, *Exercise-induced suppression of appetite: effects on food intake and implications for energy balance.* Eur J Clin Nutr, 1994. **48**(10): p. 715-24.

22. Gillman, M.W., et al., *Relationships of physical activity with dietary behaviors among adults.* Prev Med, 2001. **32**(3): p. 295-301.

23. Smith, S.R., et al., *Concurrent physical activity increases fat oxidation during the shift to a high-fat diet.* Am J Clin Nutr, 2000. **72**(1): p. 131-8.

24. Lytle, L.A., et al., *How do children's eating patterns and food choices change over time? Results from a cohort study.* Am J Health Promot, 2000. **14**(4): p. 222-8.

25. *Obesity and cardiovascular disease risk factors in black and white girls: the NHLBI Growth and Health Study.* Am J Public Health, 1992. **82**(12): p. 1613-20.

26. Kimm, S.Y., et al., *Decline in physical activity in black girls and white girls during adolescence.* N Engl J Med, 2002. **347**(10): p. 709-15.

27. Kimm, S.Y., et al., *Longitudinal changes in physical activity in a biracial cohort during adolescence.* Med Sci Sports Exerc, 2000. **32**(8): p. 1445-54.

28. *NHLBI Growth and Health Study (NGHS) Master Documentation for Limited Data Sets.* 2012.

29. IBM Corp. Released 2013. IBM SPSS Statistics for Windows, V.A., NY: IBM Corp.

30. Rolls, B.J., *Carbohydrates, fats, and satiety.* Am J Clin Nutr, 1995. **61**(4 Suppl): p. 960S-967S.

31. Tremblay, A., et al., *Impact of dietary fat content and fat oxidation on energy intake in humans.* Am J Clin Nutr, 1989. **49**(5): p. 799-805.

32. Prentice, A.M., *Manipulation of dietary fat and energy density and subsequent effects on substrate flux and food intake.* Am J Clin Nutr, 1998. **67**(3 Suppl): p. 535S-541S.

33. Starritt, E.C., D. Angus, and M. Hargreaves, *Effect of short-term training on mitochondrial ATP production rate in human skeletal muscle.* J Appl Physiol, 1999. **86**(2): p. 450-4.

34. Holloszy, J.O. and E.F. Coyle, *Adaptations of skeletal muscle to endurance exercise and their metabolic consequences.* J Appl Physiol, 1984. **56**(4): p. 831-8.

35. Tchkonia, T., et al., *Identification of depot-specific human fat cell progenitors through distinct expression profiles and developmental gene patterns.* Am J Physiol Endocrinol Metab, 2007. **292**(1): p. E298-307.

36. Knittle, J.L., et al., *The growth of adipose tissue in children and adolescents. Cross-sectional and longitudinal studies of adipose cell number and size.* J Clin Invest, 1979. **63**(2): p. 239-46.

37. Toschke, A.M., et al., *Growth around puberty as predictor of adult obesity.* Eur J Clin Nutr, 2008. **62**(12): p. 1405-11.

38. Rimm, I.J. and A.A. Rimm, *Association between juvenile onset obesity and severe adult obesity in 73, 532 women.* Am J Public Health, 1976. **66**(5): p. 479-81.

39. Anderssen, N., et al., *Change and secular trends in physical activity patterns in young adults: a seven-year longitudinal follow-up in the Coronary Artery Risk Development in Young Adults Study (CARDIA).* Am J Epidemiol, 1996. **143**(4): p. 351-62.

40. Kral, T.V., et al., *Daily food intake in relation to dietary energy density in the free-living environment: a prospective analysis of children born at different risk of obesity.* Am J Clin Nutr, 2007. **86**(1): p. 41-7.

41. Kral, T.V., et al., *Dietary energy density increases during early childhood irrespective of familial predisposition to obesity: results from a prospective cohort study.* Int J Obes (Lond), 2007. **31**(7): p. 1061-7.

42. Ello-Martin, J.A., et al., *Dietary energy density in the treatment of obesity: a year-long trial comparing 2 weight-loss diets.* Am J Clin Nutr, 2007. **85**(6): p. 1465-77.

TABLE 1. Canonical correlation analysis evaluating physical activity and confounders with diet quality indicators. Percent variance explained by first indices and first indices' standardized canonical coefficients by visit year.

			Physical Activity, Confounders								Diet Quality			
y	n	% var.	Inc	Race	Ht	Wt	Rx HAQ	Rx3d AD	HAQ	3d AD	ED	Av kcal.	Sat fat %	fiber
3	1701	66.26	0.32**	-0.64**	-0.30*	0.29†	0.14*	-0.66**	-0.03†	0.45*	-0.88	-0.55	0.35	0.23
5	1576	66.19	0.41**	-0.67**	-0.18*	0.38	0.35*	-0.54**	-0.09**	0.27**	-0.67	-0.79	0.10	0.76
7	1457	69.97	0.27**	-0.59**	-0.06*	0.10*	-0.10**	-0.46**	0.37**	0.30**	-0.57	-0.89	-0.15	0.91
8	1423	70.60	0.36**	-0.41**	-0.04**	0.16	-0.56**	-0.31**	0.89**	0.29**	-0.54	-0.65	-0.08	0.86
10	1699	74.26	0.36**	-0.48**	-0.08*	0.16*	-0.33**	-0.17**	0.72**	0.25**	-0.60	-0.49	-0.17	0.65

† significance at $P < 0.1$; * significance at $P < 0.05$; ** significance at $P < 0.001$; for dependant variates significance is evaluated with a univariate F test for association with first indices canonical correlation.

Abbreviations: 3 day activity diary score (3d AD), average caloric intake (Av kcal), average dietary saturated fat percent (Sat fat %), average energy density (ED), average fiber intake (fiber), habitual physical activity questionnaire score (HAQ), height (Ht), income category (Inc), percent variance (% var), race by 3 day AD (Rx3d AD), race by HAQ (RxHAQ), weight (Wt), year (y).

TABLE 2. Canonical correlation analysis evaluating health behaviors and confounders (obesity correlates) with body composition. Percent variance explained by first indices and first indices' standardized canonical coefficients by visit year.

			Obesity Correlates										Body Composition	
y	n	% var.	Inc	Race	Rx HAQ	Rx3d AD	HAQ	3d AD	ED	Av kcal	Sat fat %	fiber	BMI	BF%
3	1693	81.43	0.21**	-0.50**	0.33**	0.11**	-0.36**	-0.29**	0.07*	0.05*	-0.21**	-0.05**	-1.80	1.12
5	1557	75.28	0.38**	-0.32**	0.01**	-0.45**	0.06**	0.18**	0.16*	0.30**	-0.12*	-0.26*	-1.61	0.75
7	1412	62.65	0.32**	-0.71**	0.24**	0.14*	-0.04**	-0.22	0.18	-0.02*	0.28†	0.26**	-1.19	0.22
8	1378	63.45	0.15**	-0.67**	0.37**	-0.64**	-0.19**	0.18**	0.18	0.07*	0.17*	0.03*	-1.73	0.90
10	1679	83.47	0.38**	-0.68**	-0.11**	0.11**	0.42**	-0.28*	0.32	0.14	0.08	0.06**	-1.14	0.16

† significance at P < 0.1; * significance at P < 0.05; ** significance at P < 0.001; for dependant variates significance is evaluated with a univariate F test for association with first indices canonical correlation.

Abbreviations: 3 day activity diary score (3d AD), average caloric intake (Av kcal), average dietary saturated fat percent (Sat fat %), average energy density (ED), average fiber intake (fiber), habitual physical activity questionnaire score (HAQ), income category (Inc), body fat percent (BF%), percent variance (% var), race by 3 day AD (Rx3d AD), race by HAQ (RxHAQ), year (y).

2.9 Supplemental Tables for Reviewers

TABLE S1. Bivariate results; Spearman's rho correlation for income, race, habitual physical activity questionnaire score (HAQ), 3 day activity diary score (3d AD), average energy density (ED), average caloric intake (Av kcal), average dietary saturated fat percent (Sat fat %), average fiber intake (fiber) by visit year

	Year	Income	Race	HAQ	3d AD	ED	Av kcal	Satfat%	Fiber	BMI	BF%
Income	3	1	-.348**	.069**	-.056	-.176**	-.007	-.090**	.057	-.114**	-.034
	5	1	-.358**	.122**	.036	-.164**	-.010	-.175**	.128**	-.147**	-.079**
	7	1	-.354**	.301**	.012	-.185**	-.053	-.156**	.132**	-.144**	-.135**
	8	1	-.348**	.289**	-.028	-.154**	-.074**	-.211**	.138**	-.149**	-.114**
	10	1	-.357**	.317**	-.067**	-.207**	-.083**	-.238**	.144**	-.172**	-.163**
Race	3		1	-.090**	-.088**	.208**	.088**	.020	-.022	.188**	.087**
	5		1	-.193**	-.104**	.250**	.099**	.079**	-.064**	.185**	.094**
	7		1	-.346**	-.164**	.300**	.133**	.120**	-.121**	.200**	.121**
	8		1	-.291**	-.075**	.276**	.103**	.142**	-.115**	.207**	.108**
	10		1	-.348**	-.013	.373**	.111**	.206**	-.119**	.207**	.162**
HAQ	3			1	.263**	-.038	.017	-.013	.042	-.060**	-.086**
	5			1	.285**	-.095**	.020	-.045	.075**	-.090**	-.120**
	7			1	.249**	-.153**	.007	-.138**	.199**	-.141**	-.152**
	8			1	.220**	-.129**	-.014	-.192**	.156**	-.128**	-.155**
	10			1	.103**	-.172**	-.066**	-.212**	.202**	-.144**	-.159**
AD	3				1	.004	.056	.004	.064**	.003	-.085**
	5				1	-.001	.082**	.062**	.075**	-.028	-.081**
	7				1	-.049	.086**	-.017	.127**	.003	-.005
	8				1	-.011	.096**	-.020	.136**	.052	.031
	10				1	-.071**	.050	-.047	.048	.078**	.062**
ED	3					1	.249**	.342**	.064**	-.029	-.077**
	5					1	.291**	.382**	.094**	-.056	-.084**
	7					1	.290**	.449**	.060	-.035	-.031
	8					1	.261**	.481**	.074**	-.053	-.045
	10					1	.238**	.458**	.037	-.024	.001
Kcal	3						1	.102**	.678**	-.046	-.097**
	5						1	.195**	.664**	-.127**	-.148**
	7						1	.209**	.627**	-.069**	-.089**
	8						1	.231**	.620**	-.066**	-.082**
	10						1	.221**	.575**	-.028	-.049
Satfat%	3							1	-.154**	.046	-.010
	5							1	-.068**	.025	.017
	7							1	-.114**	-.040	-.034
	8							1	-.093**	-.019	.000
	10							1	-.151**	.008	.016
Fiber	3								1	-.092**	-.123**
	5								1	-.113**	-.118**
	7								1	-.102**	-.117**
	8								1	-.089**	-.076**
	10								1	-.088**	-.095**

Table S1 continued

BMI	3									1	.835**
	5									1	.853**
	7									1	.864**
	8									1	.873**
	10									1	.900**

** significance at $P < 0.001$; two-tailed t test

TABLE S2. Percent variance (% var.) explained by first indices and first indices' canonical correlation (CC). Standardized canonical coefficients for physical activity and confounders [income category (Inc), race, maturation stage (MS), height (Ht), weight (Wt), race by HAQ (RxHAQ), race by 3 day AD (Rx3d AD), habitual physical activity questionnaire score (HAQ), 3 day activity diary score (3d AD)],and diet quality indicators [average energy density (ED), average caloric intake (Av kcal), average dietary saturated fat percent (Sat fat %), average fiber intake (fiber)] by visit year (y).

				Physical Activity, Confounders									Diet Quality			
y	n	% var.	CC	Inc	Race	MS	Ht	Wt	Rx HAQ	Rx3d AD	HAQ	3d AD	ED	Av kcal.	Sat fat %	fiber
3	1701	66.26	0.29	0.32**	-0.64**	0.32	-0.30*	0.29†	0.14*	-0.66**	-0.03†	0.45*	-0.88	-0.55	0.35	0.23
5	1576	66.19	0.34	0.41**	-0.67**	0.02*	-0.18*	0.38	0.35*	-0.54**	-0.09**	0.27**	-0.67	-0.79	0.10	0.76
7	1457	69.97	0.42	0.27**	-0.59**	-0.02*	-0.06*	0.10*	-.10**	-0.46**	0.37**	0.30**	-0.57	-0.89	-0.15	0.91
8	1423	70.60	0.41	0.36**	-0.41**	-0.00	-0.04**	0.16	-0.56**	-0.31**	0.89**	0.29**	-0.54	-0.65	-0.08	0.86
10	1699	74.26	0.46	0.36**	-0.48**	n/a	-0.08*	0.16*	-0.33**	-0.17**	0.72**	0.25**	-0.60	-0.49	-0.17	0.65

† significance at $P < 0.1$; * significance at $P < 0.05$; ** significance at $P < 0.001$; for dependant variates significance is evaluated with a univariate F test for association with first indices canonical correlation.

TABLE S3. Cohort stratified by race (black). Percent variance (% var) explained by first indices and first indices' canonical correlation (CC). Standardized canonical coefficients for physical activity and confounders [income category (Inc), maturation stage (MS), height (Ht), weight (Wt), habitual physical activity questionnaire score (HAQ), 3 day activity diary score (3d AD)],and diet quality indicators [average energy density (ED), caloric intake (Av kcal), average dietary saturated fat percent (Sat fat %), average fiber intake (fiber)] by visit year (y).

				Physical Activity, Confounders						Diet Quality			
y	n	% var.	CC	Inc	MS	Ht	Wt	HAQ	3d AD	ED	Av kcal	Sat fat%	fiber
3	870	67.24	0.22	0.23*	0.48	-0.50	0.40	0.00	-0.70**	-0.43	-0.39	0.11	-0.53
5	815	70.17	0.29	0.72**	-0.02	-0.21	0.49*	0.37*	-0.47**	-0.37	-0.91	-0.26	0.80
7	741	52.78	0.24	0.38*	0.01†	-0.25*	0.44*	0.21*	-0.79**	-0.31	-0.81	-0.21	0.02
8	734	57.52	0.23	0.51**	0.09	-0.35†	0.65†	-0.00	-0.62**	-0.46	-0.70	-0.19	-0.00
10	861	56.70	0.25	0.72**	n/a	-0.11	0.49†	0.19*	-0.41**	-0.12	-0.72	-0.58	0.19

† significance at P < 0.1; * significance at P < 0.05; ** significance at P < 0.001; for dependant variates significance is evaluated with a univariate F test for association with first indices canonical correlation.

TABLE S4. Cohort stratified by race (white). Percent variance (% var) explained by first indices and first indices' canonical correlation (CC). Standardized canonical coefficients for physical activity and confounders [income category (Inc), maturation stage (MS), height (Ht), weight (Wt), habitual physical activity questionnaire score (HAQ), 3 day activity diary score (3d AD)], and diet quality indicators [average energy density (ED), caloric intake (Av kcal), average dietary saturated fat percent (Sat fat %), average fiber intake (fiber)] by visit year (y).

				Physical Activity, Confounders						Diet Quality			
y	n	% var.	CC	Inc	MS	Ht	Wt	HAQ	3d AD	ED	Av kcal	Sat fat%	fiber
3	831	48.80	0.17	0.86**	0.17*	0.35*	-0.10*	0.14	-0.10	-0.79	0.33	-0.30	0.15
5	761	62.86	0.27	0.71**	-0.39*	0.37†	-0.35*	-0.01†	-0.00*	0.22	0.41	-0.69	0.41
7	716	77.85	0.34	0.59**	-0.04	0.02†	-0.01†	0.69**	0.02†	0.08	-0.15	-0.38	0.93
8	689	71.13	0.36	0.53**	0.07	0.16**	-0.09	0.65**	0.12*	0.05	-0.26	-0.61	0.78
10	838	80.26	0.38	0.55**	n/a	-0.01**	0.05	0.73**	0.06*	-0.11	-0.32	-0.45	0.79

† significance at $P < 0.1$; * significance at $P < 0.05$; ** significance at $P < 0.001$; for dependant variates significance is evaluated with a univariate F test for association with first indices canonical correlation.

TABLE S5. Percent variance (% var.) explained by first indices and first indices' canonical correlation (CC). Standardized canonical coefficients for obesity correlates [income category (Inc), race, maturation stage (MS), height (Ht), weight (Wt), race by HAQ (RxHAQ), race by 3 day AD (Rx3d AD), habitual physical activity questionnaire score (HAQ), 3 day activity diary score (3d AD), average energy density (ED), average caloric intake (Av kcal), average dietary saturated fat percent (Sat fat %), average fiber intake (fiber)], and body composition [BMI, body fat percent (BF%)] by visit year (y).

				Obesity Correlates											Body Composition	
y	n	% var.	CC	Inc	Race	MS	Rx HAQ	Rx3d AD	HAQ	3d AD	ED	Av kcal	Sat fat %	fiber	BMI	BF%
3	1693	81.43	0.39	0.21**	-0.50**	-0.77**	0.33**	0.11**	-0.36**	-0.29**	0.07*	0.05*	-0.21**	-0.05**	-1.80	1.12
5	1557	75.28	0.35	0.38**	-0.32**	-0.56**	0.01**	-0.45**	0.06**	0.18**	0.16*	0.30**	-0.12*	-0.26*	-1.61	0.75
7	1412	62.65	0.27	0.32**	-0.71**	-0.27**	0.24**	0.14*	-0.04**	-0.22	0.18	-0.02*	0.28†	0.26**	-1.19	0.22
8	1378	63.45	0.30	0.15**	-0.67**	-0.11*	0.37**	-0.64**	-0.19**	0.18**	0.18	0.07*	0.17*	0.03*	-1.73	0.90
10	1679	83.47	0.29	0.38**	-0.68**	n/a	-0.11**	0.11**	0.42**	-0.28*	0.32	0.14	0.08	0.06**	-1.14	0.16

† significance at P < 0.1; * significance at P < 0.05; ** significance at P < 0.001; for dependant variates significance is evaluated with a univariate F test for association with first indices canonical correlation.

TABLE S6. Cohort stratified by race (black). Percent variance (% var) explained by first indices and first indices' canonical correlation (CC). Standardized canonical coefficients for obesity correlates [income category (Inc) maturation stage (MS), height (Ht), weight (Wt), habitual physical activity questionnaire score (HAQ), 3 day activity diary score (3d AD), average energy density (ED), average caloric intake (Av kcal), average dietary saturated fat percent (Sat fat %), average fiber intake (fiber)], and body composition [BMI, body fat percent (BF%)] by visit year (y).

				Obesity Correlates								Body Composition	
y	n	% var.	CC	Inc	MS	HAQ	3d AD	ED	Av kcal	Sat fat %	fiber	BMI	BF%
3	865	63.89	0.29	0.25**	-0.92**	0.02	-0.24*	0.07*	0.09*	-0.31*	-0.08†	-1.91	1.27
5	802	55.82	0.26	0.02**	0.66**	-0.43*	0.02**	-0.31*	-0.57*	-0.05*	0.37	-0.50	1.43
7	714	89.14	0.25	0.44*	-0.45*	0.50*	-0.10	0.09	0.17*	0.29†	0.32*	0.81	-1.66
8	701	56.55	0.23	0.32*	0.05	0.70**	-0.26*	0.30†	0.66*	-0.34*	-0.18†	0.72	-1.60
10	851	75.32	0.18	0.43*	n/a	0.36*	-0.31	0.53**	0.35†	0.19†	0.12	-0.70	-0.32

† significance at P < 0.1; * significance at P < 0.05; ** significance at P < 0.001; for dependant variates significance is evaluated with a univariate F test for association with first indices canonical correlation.

TABLE S7. Cohort stratified by race (white). Percent variance (% var) explained by first indices and first indices' canonical correlation (CC). Standardized canonical coefficients for obesity correlates [income category (Inc) maturation stage (MS), height (Ht), weight (Wt), habitual physical activity questionnaire score (HAQ), 3 day activity diary score (3d AD), average energy density (ED), average caloric intake (Av kcal), average dietary saturated fat percent (Sat fat %), average fiber intake (fiber)], and body composition [BMI, body fat percent (BF%)] by visit year (y).

				Obesity Correlates								Body Composition	
y	n	% var.	CC	Inc	MS	HAQ	3d AD	ED	Av kcal	Sat fat %	fiber	BMI	BF%
3	828	81.76	0.39	0.22*	-0.84**	-0.20**	-0.23**	0.09	0.05	-0.23*	-0.09*	-1.76	1.17
5	755	88.34	0.36	0.51**	-0.70**	0.12*	-0.02*	0.28*	0.13*	-0.21	-0.06*	-1.14	0.17
7	698	66.57	0.24	0.57**	-0.43*	0.40**	-0.13	0.30*	0.01	0.04*	0.22*	-0.26	-0.76
8	677	76.35	0.27	0.47**	-0.40*	0.56**	-0.29	0.30	0.17	-0.15	0.10	0.11	-1.10
10	828	80.54	0.26	0.70**	n/a	0.56**	-0.28	0.10*	0.12	0.03	0.02*	0.51	0.52

† significance at $P < 0.1$; * significance at $P < 0.05$; ** significance at $P < 0.001$; for dependant variates significance is evaluated with a univariate F test for association with first indices canonical correlation.

2.10 Figures

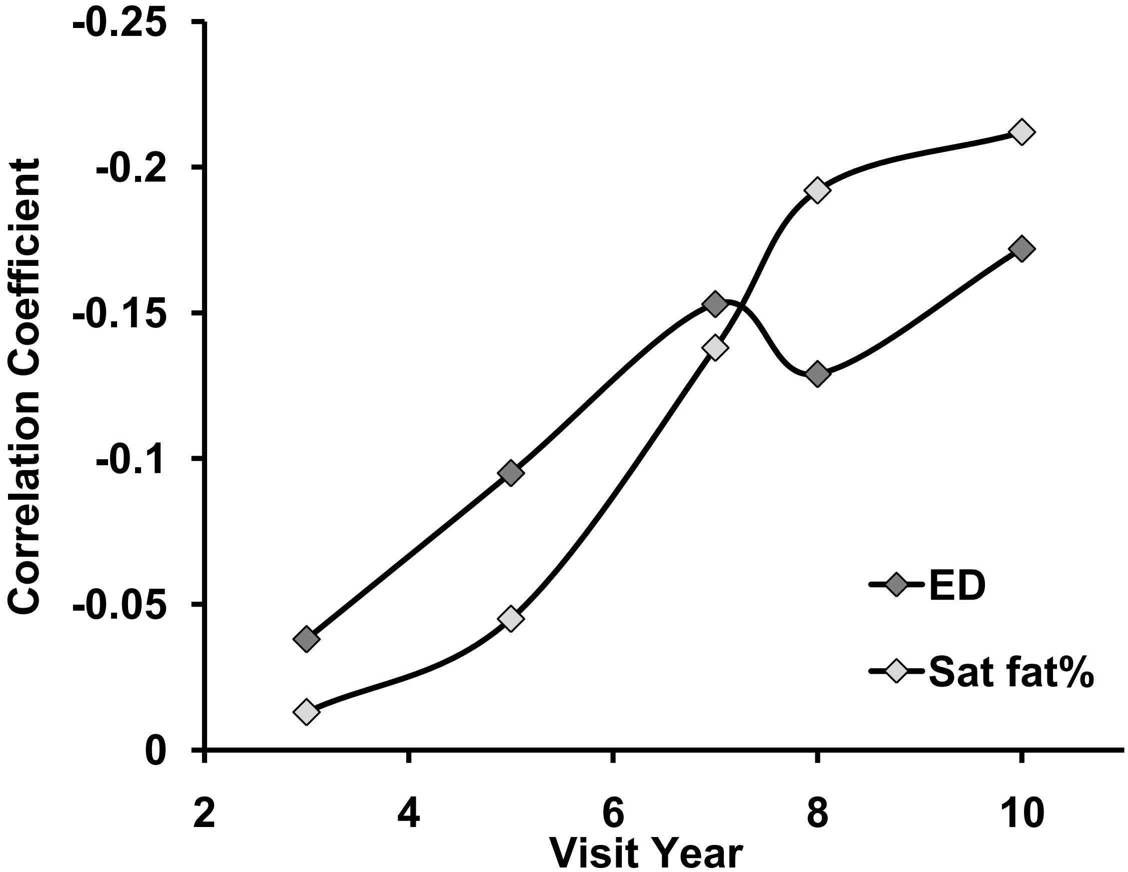

FIGURE 1. Spearman's rho correlation coefficients. Figure 1 a: correlation between habitual physical activity and average energy density (ED) and dietary saturated fat percent (Sat fat %) by visit year. Correlation is significant (two-tailed t, P < 0.001) for year 5, 7, 8, and 10 for correlation with ED, and for year 7, 8, and 10 for correlation with Sat fat %.

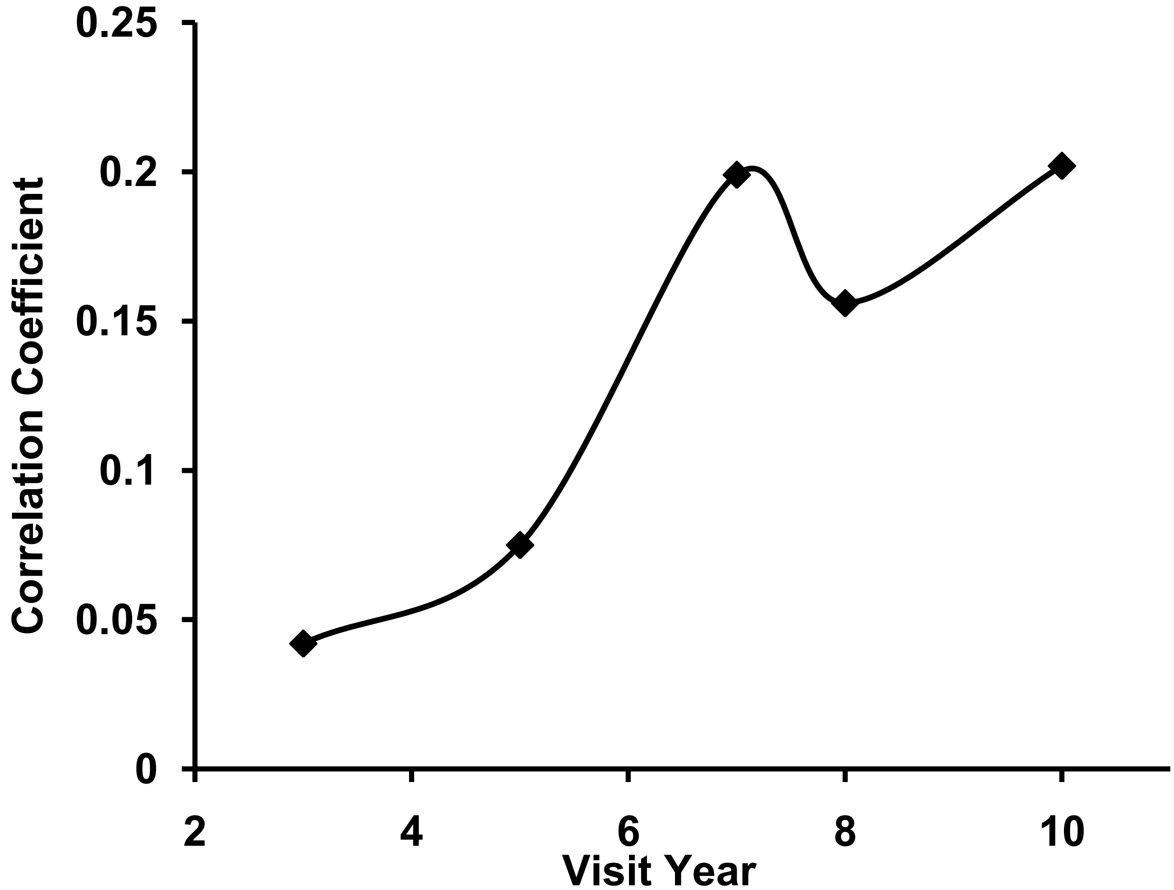

FIGURE 1. Spearman’s rho correlation coefficients. Figure 1 b: correlation between habitual physical activity and fiber intake by visit year. Correlation is significant (two-tailed t, P < 0.001) for year 5, 7, 8, and 10 for correlation fiber.

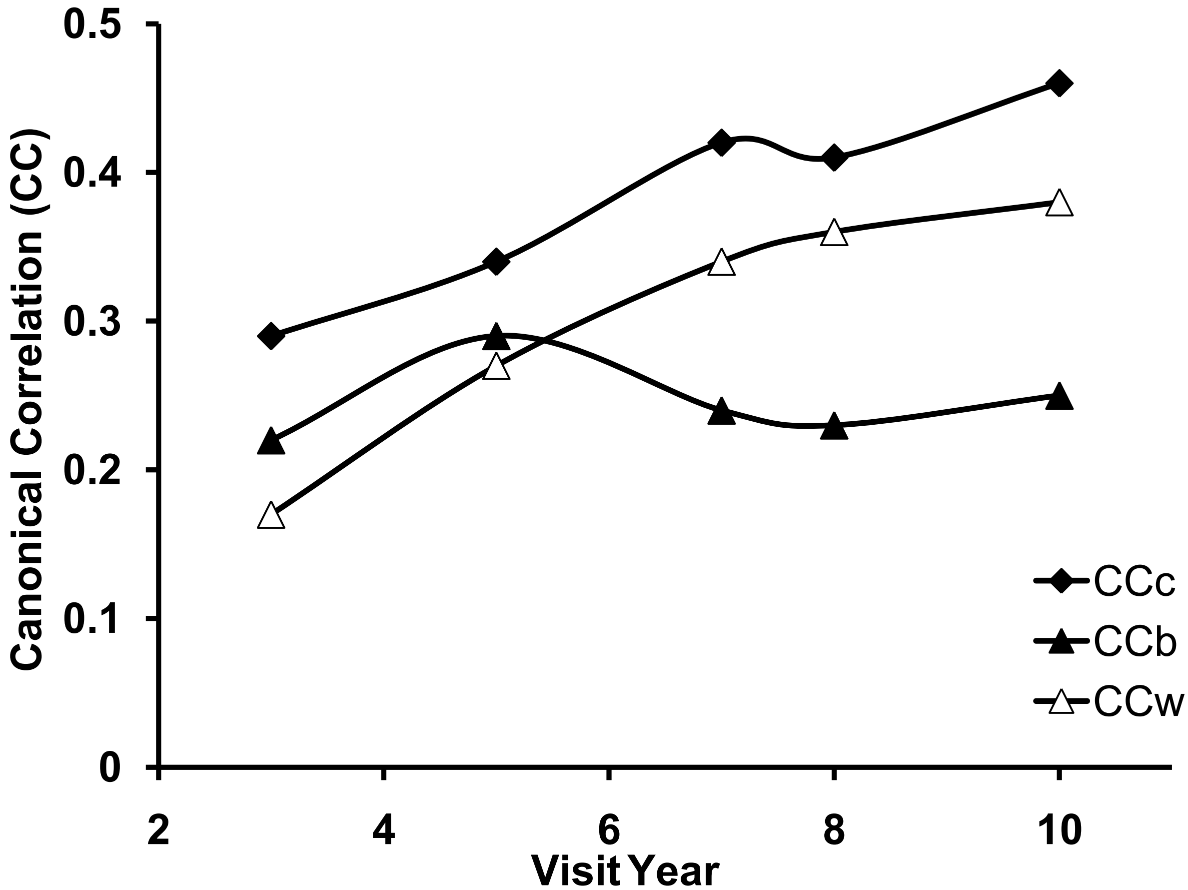

FIGURE 2. Canonical correlation of physical activity and confounders with diet quality indicators by visit year. Physical activity and confounders: income category, race, maturation stage, height, weight, habitual physical activity questionnaire score (HAQ), 3 day activity diary score (3d AD), racial interaction HAQ, racial interaction 3d AD; diet quality indicators: average energy density, average caloric intake, average dietary saturated fat percent, average fiber intake. Lines represent stratified data from black (CCb) and white (CCw) girls and combined (CCc) data.

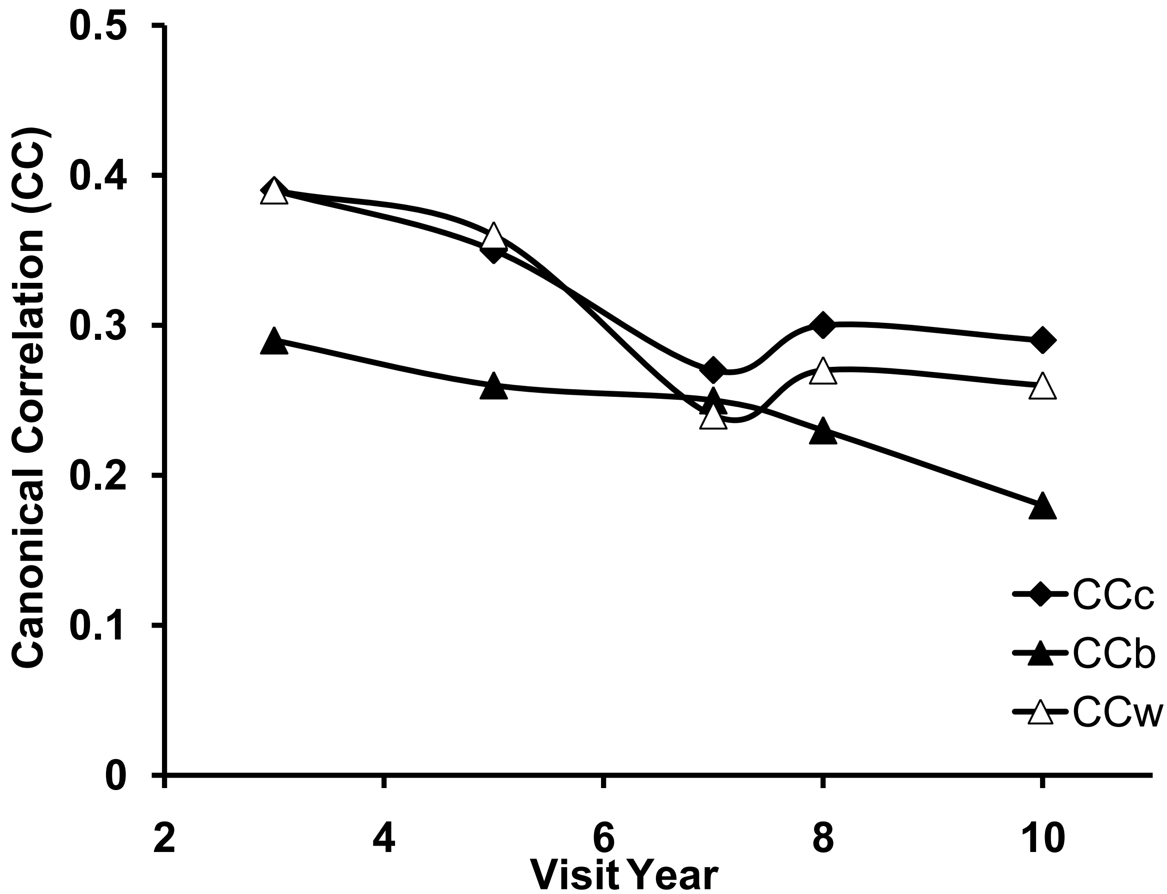

FIGURE 3. Canonical correlation between obesity correlates and body composition by visit year. Obesity correlates: income category, race, maturation stage, habitual physical activity questionnaire score (HAQ), 3 day activity diary score (3d AD), racial interaction HAQ, racial interaction 3d AD, average energy density, average caloric intake, average dietary saturated fat percent, average fiber intake; body composition: BMI, body fat percent. Lines represent stratified data from black (CCb) and white (CCw) girls and combined (CCc) data.