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Setting the state for childhood fitness: Dietary energy density is associated with locomotor development in US children

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Abstract

Objective: Childhood obesity is an ongoing public health problem. Researchers have identified dietary energy density (ED, kcal/g), an established marker for diet quality, and sedentary behavior as risk factors for obesity during childhood, but little is known about the relationship between diet and factors associated with fitness during early childhood and adolescence. The objective of the present study was to evaluate the relationship between diet quality and various markers of physical fitness, including locomotor development and enjoyment of physical activity in nationally representative sample of US children.

Methods: A secondary data analysis of 1,518 children age 3-15 years old who participated in the 2012 National Health and Nutrition Examination Survey National Youth Fitness Survey (NYFS) was completed for this study. The dataset contains information about dietary intake, locomotor development, and physical activity for all participants. Dietary intake information was collected using 24-hour recall, and assessment of diet quality involved calculation of dietary energy density. Multivariable linear regression was used to compare stratum-specific mean estimates of dietary energy density for children adjusting for age, sex, race, household income, and body mass index percentile.

Results: In the present study, we observed a negative linear relationship between dietary energy density and locomotor skills (p-trend=0.01); children with the lowest locomotor skill scores had higher dietary ED than children with the highest locomotor skill scores (1.85±0.03kcal/g vs. 1.56±0.07kcal/g p=0.002). In older children, a negative linear trend between dietary ED and self-reported enjoyment of participation in physical education or recess ($p<0.0001$) was observed.

Conclusions: The results indicate that dietary ED in early childhood is inversely associated with locomotor skill score, and diet in older children corresponds with enjoyment of physical activity in older children. Consuming a diet low in ED may therefore represent dietary behaviors that support physical activity in children.

Keywords: Locomotor, NHANES, physical activity, diet, children

1.INTRODUCTION

Childhood obesity is an ongoing public health problem.[1] Though obesity is a multifactorial issue, engagement in physical activity may play a role. The 2008 Physical Activity Guidelines for Americans provided the first ever specific recommendation for exercise types and amounts for children and adults of all ages.[2] Despite the publicity surrounding national guidelines, adherence to the guidance has been low. [3,4] Recent national data also demonstrates that approximately 60% of US children and adolescents engage in sedentary behaviors.[5] National surveillance data demonstrates that fewer than one in five adolescents meet the recommended exercise amount.[4]

Physical exercise is especially important during the preschool years when fundamental movement skills (FMS) are rapidly developing. Locomotor skills are a component of FMS. These skills provide the foundation for complex movements needed for physical activity. Proficient FMS are associated with increased physical activities and sustained engagement in these activities. [6] Children's FMS dramatically improve during the preschool years but remain underdeveloped until about 10-12 years of age.[7] Engaging in locomotor activities during early childhood is essential to developing these skills and acquiring competent motor abilities. There is a body of evidence that suggests that locomotor skills are associated with physical activity in young children, with better locomotor skill development associated with higher levels of activity.[8,9] Locomotor development may therefore play an important role in the development of early exercise habits in children, as children with better locomotor skills can more easily engage in physical activities and are more likely to choose physical activities compared to their less adept peers.[10] The association between locomotor skill and physical activity is not isolated to young children. Research has demonstrated that higher locomotor skills are associated with greater amounts of physical activity in older children and pre-teens.[11]

Simultaneously, overweight children often present with delayed or deficient locomotor skills, participate in fewer physical activities, and have lower perceived motor competencies than non-overweight children.[10,12] Whether these characteristics contribute to decreased enjoyment of physical activities for overweight children is still undetermined. Research has yielded inconsistent results with some reporting overweight children experiencing lower levels of enjoyment compared to their normal weight peers and others not finding a difference.[12,13] Maintaining a healthy weight and engaging in physical activities at a young age may improve children's enjoyment of these activities and lead to continued participation in physical activities in the future.

Beyond engagement in physical activities and sedentary behaviors, dietary behaviors are an important factor related to obesity risk in children. Few studies evaluate the relationship between dietary intake and physical activity. One study provides evidence that diet quality is positively associated with physical activity in older children.[14] The majority of studies focus on dietary intake as it relates to cardiometabolic health, [15] or nutrient deficiency related to improper cognitive or motor

development.[16] It is well established in the literature that micronutrient deficiencies, including deficiencies in Vitamin D and iron, can lead to developmental abnormalities that may impact motor development and physical performance;[17,18] and low intake of other nutrients, including fiber may be associated with obesity in children.[19] However, when understanding the association between dietary behaviors and obesity, it is important to consider the overall diet. There are several dietary behaviors associated with obesity in children, many of which include markers of diet quality. Dietary energy density (ED) is an established marker for diet quality and is also associated with body weight status in US children and adults.[20,21] Low ED diets are associated with greater micronutrient intake, lower fat intake, higher fruit and vegetable intake, and greater fiber content in children.[21] A low-ED diet may therefore be supportive of locomotor development in young children as low-ED diets would be supportive of nutrient adequacy in children and also less likely to be associated with obesity in children. Identification of dietary patterns, such as dietary energy density, that are associated with locomotor skills may be an important piece of the puzzle when it comes to understanding risk factors for childhood obesity; at present the field of dietary intake and locomotor development remains understudied. Identification of dietary behaviors supportive of locomotor skill development in young children and dietary behaviors supportive of physical activity in older children and adolescents remains a priority for public health officials.

The objective of the present study was to evaluate the association between dietary energy density and (1) locomotor skill score among young children and (2) enjoyment of physical activity among children and adolescences in a nationally representative sample of US children.

2.METHODS

Data Source

The NHANES National Youth Fitness Survey. The National Health and Nutrition Examination - National Youth Fitness Survey, was a specialized nationally representative cross sectional survey of US children age 3 – 15 years that was designed to assess the health and fitness of US children using a variety of interviews, surveys and assessments of physical fitness.[22] The survey was conducted in 2012 by the Division of Health and Nutrition Examination Surveys, National Center for Health Statistics, part of the Centers for Disease Control and Prevention with data release updates occurring in late 2016; a total of 1,576 youth participated in the interview and examination portion of the study. Complete details regarding the NHANES NNYFS sampling methodology, data collection, and interview process are available on the NNYFS website; written consent was obtained from all subjects (https://www.cdc.gov/nchs/nnyfs/index.htm). The present study was a secondary analysis of this dataset and included 1,518 individuals with complete dietary and examination data.

Assessment of Locomotor Skill

Assessment of Locomotor Skill. Locomotor skill was assessed using the Test of Gross Motor Development – Second Edition (TGMD2) as part of the National Youth Fitness Survey.[22] This

validated test of locomotor development was administered to 336 children age 3-5 years old. Specific details of the protocol can be found in: Test of Gross Motor Development Procedures Manual available on the NNYFS website at: https://www.cdc.gov/nchs/data/nnyfs/tgmd.pdf. Briefly, for skill assessment, children are asked to engage in a series of six tasks (e.g., run, hop, slide) during which specific behavioral aspects of locomotor control are evaluated by trained assessors. To assess skills, assessors read a script (i.e., "Run as fast as you can and stop at this cone!") or read a script and also demonstrated the skill (i.e., "I am going to gallop like a horse, watch me gallop!") and scored children using a scoring guide with descriptions of performance criteria for each skill. Children who refused participation in specific skills were coded as "missing". Among participants, each task was measured twice. At the end of two trials, scores were added together. The NHANES NNYFS dataset includes both a raw score, which is calculated by adding all tasks together (range 0-48); and a standard score (standardized by child age by using exam age in months) for each child. For the present analysis, the locomotor standard score was used in order to accurately compare locomotor abilities across ages. There is not a commonly accepted method for classifying locomotor skill scores. For the purposes of this manuscript, score categories were created based on score distribution. Standardized scores were categorized as low (0-4), moderate low (5-7), moderate high (8-12) or high (>13).

Assessment of Enjoyment of Physical Activity. During the NNYFS, a questionnaire related to daily activities, leisure-time activities, and sedentary activities was asked of all participants 6-15 years of age. To assess enjoyment of physical activity, the following question was used for adolescents 12-15 years of age: "*I am going to read a statement and I want you to let me know if you strongly agree, agree, neither agree nor disagree, disagree or strongly disagree with the statement. {I enjoy participating in PE or gym class.}*" and for children age 6-11, *"I am going to read a statement and I want you to let me know if you strongly agree, agree, neither agree nor disagree, disagree or strongly disagree with the statement. {I enjoy participating in recess}"*.

Assessment of Dietary Intake

During the NNYFS, dietary data was collected using a 24-hour recall that was administered by trained interviewers using the automated multiple-pass method (AMPM), a validated tool that accurately assesses dietary intake in large groups.[23] One day of dietary recall is collected in-person at the Mobile Examination Center. A parent or caretaker served as proxy respondent for children who were younger than six years of age; a proxy was also used for children between the ages of 6-8 years, with the child present to assist with intake reporting. For children 9-11 years old, the child responded in the presence of an adult who is familiar with the child's intake; participants >12 years old answered recall interviews themselves. In order to achieve a representative data sample, dietary data is weighted in the NNYFS dataset to ensure proportional distribution of dietary data by day of the week (as to not over-represent weekend intake data), and to account for non-response

bias. As part of the national *What We Eat in America Study*, this complex sampling method allows for the dietary recall day to accurately assess the mean of the population's usual intake. Dietary energy density was calculated using the commonly accepted method of totaling the food-only energy intake (kcal) and dividing by the total gram weight of foods consumed, excluding beverages.[20,24]

Statistical Analysis

Multivariable linear regression models were constructed to compare adjusted dietary energy density with categories of locomotor skill score and enjoyment of physical activity. All data were analyzed using SAS 9.4 (SAS Institute, Cary, NC) using survey procedures to address the complex sample design of the NHANES-NNYFS, including appropriate use of strata, cluster, and weight variables. Descriptive statistics for demographic variables were computed using SAS surveymeans and surveyfreq procedures. A Taylor Series Linearization was used to approximate all standard errors (SE) for all estimates reported, and statistical comparisons of dietary energy density were evaluated using a univariate t statistic. A test for linear trend using the Wald statistic was conducted by modeling categories of locomotor skill as a continuous variable. All results are presented as least-square means and standard error adjusted for age, sex, race, household income, and body mass index category (underweight, normal weight, overweight, obese). Body mass index category was calculated based on the age-and sex-specific 5th, 85th, and 95th percentiles of the 2000 CDC growth charts.

Special considerations for the statistical analysis of enjoyment of physical activity and dietary energy density: Because children 6-11 and adolescents 12-15 were asked different questions regarding enjoyment of physical activity (children were asked about 'enjoyment of PE or recess'; children 12-15 were asked about 'PE or gym class') domain analysis was subsequently conducted for children 12-15. The domain analysis is required to properly estimate the variance in the statistical comparisons when using Taylor Series Linearization in complex survey data. The Taylor series requires that all observations with a non-zero value for the weight variable to be included, along with an indicator identifying the subpopulation of interest (in this case, children 12-15y), allowing for accurate analysis of a dataset that includes missing datapoints (in this case, children <12).

3.RESULTS

The present study included a nationally representative sample of 1,518 children age 3-15 years of age. The demographic characteristics of the sample were as follows: regarding race/ethnicity, 55.0% identified as Non-Hispanic white; 14.2% identified as Non-Hispanic Black; 23.4% Hispanic/Latino; 7.4% identified as 'other' race, including multi-racial; regarding household income, 37.6% of sample lived in households where household income was <130% the federal poverty:income ratio. The mean age of participants was 8.7±0.1 years old, and mean daily energy intake was 1874±18kcal/day. In this sample, 36% of children were overweight (18%) or obese (18%), 61% were normal weight, and 3% were

underweight, as defined by the age-and sex-specific 5th, 85th, and 95th percentiles of the 2000 CDC growth.

In the present study, we observed a negative linear relationship between dietary energy density and locomotor skills (p-trend=0.015) in a sample of 336 children age 3-5y, shown in Figure 1. Children age 3-5 with the lowest locomotor skill scores had significantly higher dietary ED than children with the highest locomotor skill scores (1.85±0.03kcal/g vs. 1.56±0.07kcal/g p=0.002). When putting this into caloric terms, this difference in energy density represents a 16% difference in caloric intake between groups. These differences in mean daily dietary energy density were observed after adjusting for sex, race/ethnic-

Figure 1. *Adjusted mean dietary energy density by locomotor skill score in a nationally representative sample of US children age 3 – 5 years old*

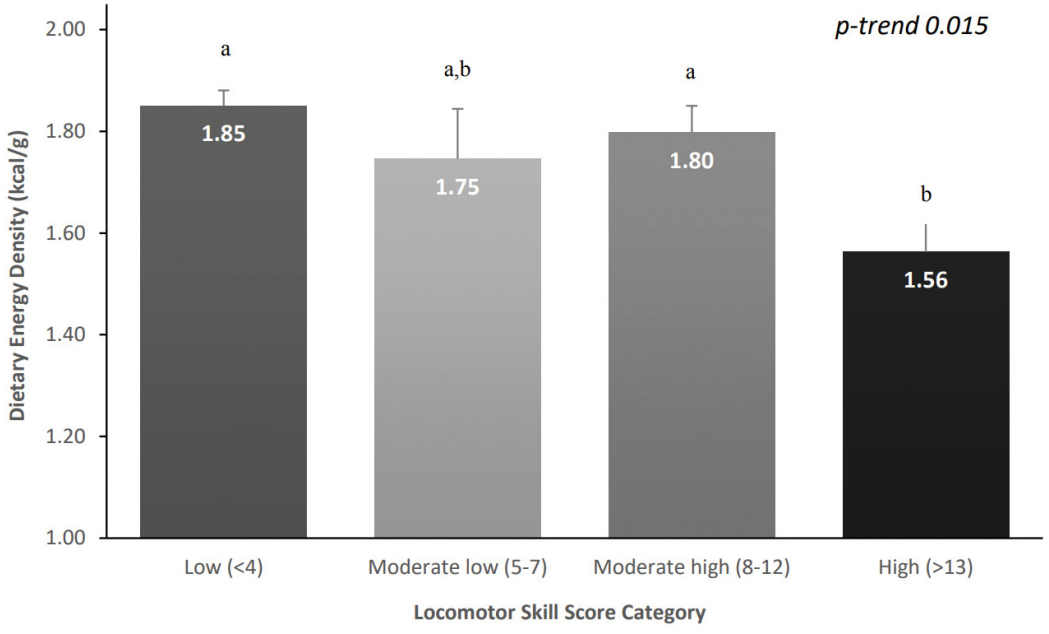

Figure 1 Legend

Adjusted mean dietary energy density (kcal/g) is presented by category of locomotor skill score, controlling for exam age in months, sex, race, household income. Standardized locomotor skill score represents a child's ability to complete a series of six movement tasks; performance on each task was assessed by a trained interviewer. A test for linear trend using the Wald statistic was conducted by modeling categories of locomotor skill as a continuous variable. Statistical differences in between-group comparisons are shown using superscripts. Bars with differing superscripts are statistically different at $p<0.05$.

ity, and household income.

In the sample of 1,182 children age 6-15, a significant negative linear trend between dietary ED and self-reported enjoyment of participation in physical education (PE) or recess ($p<0.0001$) was observed; after adjusting for age, sex, race, household income, and body mass index and is shown in Figure 2. Children who agreed or strongly agreed with enjoying physical activity (PE /recess) had a significantly lower dietary

Figure 2. *Enjoyment of physical activity and dietary energy density in a nationally representative sample of US children and adolescents age 6 – 15 years old*

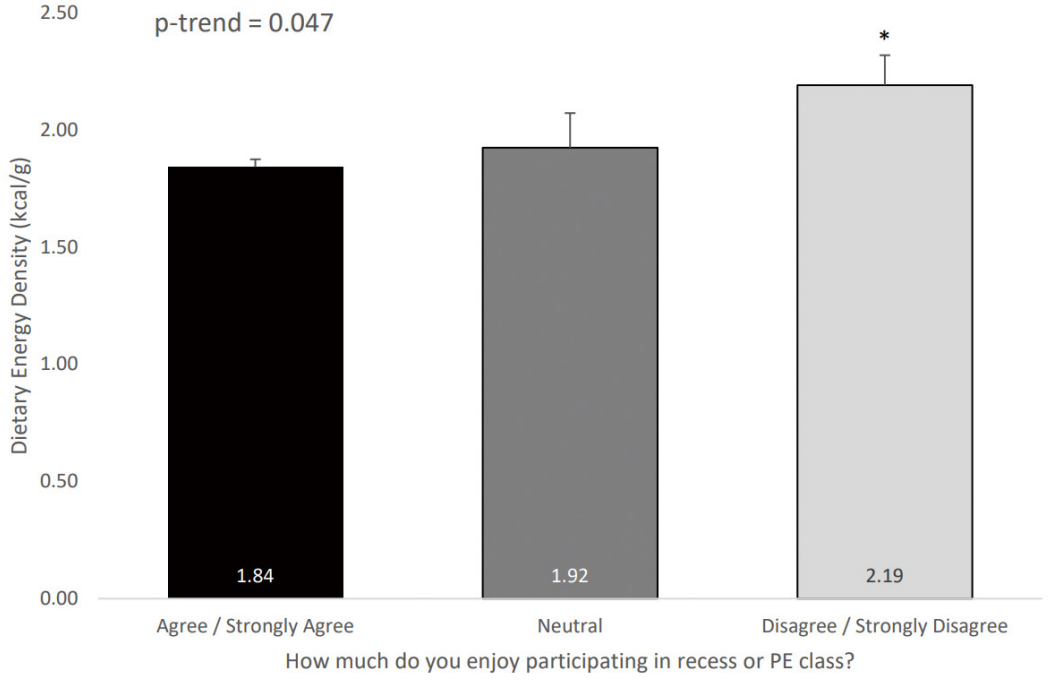

Figure 2 Legend

Adjusted mean dietary energy density (ED, kcal/g) is presented by self-reported enjoyment of physical activity adjusted for age, sex, race/ethnicity, household income. A test for linear trend using the Wald statistic was conducted by modeling categories of locomotor skill as a continuous variable. Comparisons between groups of endorsement of enjoyment of physical activity were conducted with the 'Agree/ Strongly Agree' category used as the referent group. No significant difference in mean ED between 'Agree/ Strongly Agree' and 'Neutral' endorsement of enjoyment of physical activity; statistical difference in adjusted mean ED between 'Agree/Strongly Agree' and 'Disagree / Strongly Disagree' p =0.02

energy density than children who disagreed or strongly disagreed with enjoyment of physical education / recess (1.84 ±0.04kcal vs 2.19±0.14kcal kcal/g, p=0.02). This difference would represent a 16% difference in caloric intake between groups, if both groups consumed the same gram weight of food.

In order to independently assess the association between enjoyment of physical education class, as opposed to the general "PE or recess", a separate analysis was completed for adolescents age 12-15 (n=484). In this subsample adolescents, the same relationship was observed. Children who endorsed enjoyment of PE had significantly lower dietary energy density than children who disagreed with enjoyment of PE (1.89±0.05 kcal vs 2.37±0.11kcal kcal/g, p=0.0008), corresponding to a difference of approximately 20% lower caloric intake if children in both groups consumed the same gram weight of food.

4.DISCUSSION

In this nationally representative sample of children age 3-15, dietary energy density was associated with locomotor score and enjoyment of physical activity. In preschool age children (3-5y), children with high standardized locomotor skill scores had significantly lower dietary energy density (a marker for diet quality) than those with poor locomotor skill scores. This finding indicates that children with higher diet quality also have greater locomotor skill development when compared with their same-age peers. This is the first study of our knowledge to evaluate the association between dietary energy density and locomotor skill score. It has been consistently demonstrated that there is an association between how a child scores on FMS, which includes locomotor abilities, and their physical ability in later years.[25] Previous research has demonstrated that children with lower levels of motor coordination were more likely to drop out of physical activities at a greater rate than their proficient peers. This demonstrates that a high level of movement skill proficiency in early childhood may result in higher levels of physical activity into adulthood.[25] In addition, fundamental movement skills in childhood can also play an important role in the development and maintenance of physical fitness into adulthood.[26] These findings are somewhat reflected in our analysis when identifying that children and adolescents who enjoy participating in physical activity have a lower dietary ED than those who do not enjoy physical activity.

The link between dietary energy density and physical movement ability may represent important social determinants of health, particularly for underserved populations. Prior analysis of data from the National Youth Fitness Survey demonstrated that children from lower income households and those from racial or ethnic minority groups have lower locomotor skill scores.[27] The present study results may be particularly relevant to minority and low-income children that have higher incidences of obesity, demonstrate poor motor competencies, have limited access to healthy food options and less opportunities for physical activity.[28] As a construct for dietary behavior, consuming a diet low in energy density can be applied to any type of cuisine, at any price point.[29] Future work that identifies strategies for communicating the importance of a low-ED diet

may be helpful in reducing the disproportionate burden of disease in various communities.

In addition to the previously established relationship between dietary energy density and body weight status in children,[20,24] diets low in energy density are also associated with better diet quality and confer higher intake of valuable micronutrients, as well as fruits and vegetables. This intake of micronutrients, including antioxidant-rich fruits and vegetables, plays a physiological role in supporting physical activity. Diets low in energy density and high in antioxidant-rich fruits and vegetables can provide micronutrients including B6 and riboflavin that support energy production during physical activity, and antioxidants like vitamin C that may support oxidative stress reduction following.[30] Additionally, it is possible that diets lower in energy density are higher in overall moisture content, contributing to hydration status and subsequently supporting physical activity. Consuming a diet low in energy density may therefore be a health behavior that supports locomotor skill development in early childhood, and may also support fitness in later adolescence.

There are several strengths to the present study. The National Youth Fitness Survey provides data from a nationally representative sample of US children, making the results highly generalizable. Use of validated tools for assessing locomotor skill development and collecting dietary recall data add to the strength of the observed relationships.[22] The study is not without limitations. Though the data is nationally representative, the cross-sectional nature of the data allows for determination of association, but not casual relationships nor does it allow for observation of long-term intake patterns. As cross-sectional studies provide data from one point in time, there is no way of knowing causal direction – diet may influence physical activity, but the inverse may also be true. Additionally, as with all dietary studies, collection of recall data may be prone to bias, particularly among young children.[31] The NNYFS, however, uses all statistical and methodological procedures possible to allow for accurate assessment of dietary intake data, and results can be used to determine the mean of the population's usual intake.

5.CONCLUSION

Diets low in energy density are associated with greater locomotor ability score, which may confer greater abilities to maintain physical fitness and continue physical activity in later life. Children and adolescents who endorse enjoyment of physical activity have lower dietary ED than the children who do not enjoy physical activity. This is the first study to identify dietary energy density as a factor associated with physical activity in children. Educational strategies that promote a healthy diet low in energy density may play a role in setting the stage for childhood fitness and development of healthy habits that reduce risk for disease in later life.

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STATEMENT OF AUTHOR CONTRIBUTIONS

JV conceptualized the study and performed initial data analysis. ET performed data analysis. JV and ET wrote the first draft of the manuscript with contributions from DM. All authors reviewed and commented on subsequent drafts of the manuscript.

STATEMENT OF POTENTIAL CONFLICT OF INTEREST

Jacqueline A. Vernarelli – no conflicts of interest
Emma Turchick – no conflicts of interest
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