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ORIGINAL RESEARCH

Epidemiological Transition in Physical Activity and Sedentary Time in Children

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Background: To determine if children's moderate to vigorous physical activity (MVPA) and sedentary time varied across levels of household income in countries at different levels of Human Development Index (HDI), consistent with the theory of epidemiological transition. **Methods**: Data from 6548 children (55% girls) aged 9–11 years from 12 countries at different HDI levels are used in this analysis to assess MVPA and sedentary time (measured using ActiGraph accelerometers) across levels of household income. Least-square means are estimated separately for boys and girls at the estimated 10th, 50th, and 90th percentiles of HDI for the sample. **Results**: For boys, time in MVPA is negatively associated with income at the 10th and 50th percentiles of HDI (both $P < .002$). For girls, time in MVPA is negatively associated with income at the 10th and 50th percentiles of HDI (all $P < .01$) and positively related with income at the 90th percentile ($P = .04$). Sedentary time is positively associated with income at the 10th percentile of HDI for boys ($P = .03$), but not for girls. **Conclusions**: Results support the possibility of an epidemiological transition in physical activity, with lower levels of MVPA observed at opposite levels of income depending on the HDI percentile. This phenomenon was not observed for sedentary time.

Keywords: accelerometry, epidemiology, pediatrics, sedentary behavior, youth

The theory of epidemiologic transition, which characterizes long-term trends and patterns in morbidity and mortality associated with stages of human development,[1] has been applied to understand the emergence of obesity in low- to middle-income countries.[2,3] Human development is commonly assessed at the country level with the Human Development Index (HDI), a composite statistic developed by the United Nations Development Programme, which includes data on life expectancy, education, and per capita income indicators. As countries transition from lower to higher levels of HDI, there are often consequences with respect to lifestyle behaviors, such as decreases in physical activity[4] and increases in the consumption of "Western"-style diets.[5] For example, using cross-sectional data, it was previously reported that among children, obesity prevalence, body fat percentage, and body mass index *z* scores increased linearly across levels of household income within country in countries at lower levels of HDI (10th percentile), but decreased linearly with higher incomes in countries at higher levels of HDI (90th percentile).[6] Although long-term longitudinal observations are needed to confirm this epidemiological transition of obesity within countries, cross-sectional data comparing countries at different levels of HDI can be indicative of epidemiological transitions related to obesity and lifestyle behaviors.

While a number of studies have investigated the influence of socioeconomic status (SES) on obesity and the presence of an epidemiological transition for obesity,[5,7–10] only a limited number of multicountry studies have attempted to investigate the effects of human development on levels of physical activity.[4,11] For example, Shoham et al[11] investigated the association between car ownership by adults (as a proxy indicator of SES) and objectively measured moderate to vigorous physical activity (MVPA) among 5 countries at different HDI levels and found that those without cars accumulated more MVPA, independent of the HDI of the country. It is possible that children's physical activity (particularly MVPA) and sedentary time can be associated with household income, and this relationship may differ by a country's level of human development.

Some studies have documented associations between family SES and physical activity among children,[12] but the majority of those studies used questionnaire-based estimates of physical activity and were conducted in a single high-HDI country. Sedentary time is also of interest in this age group because it can have detrimental health effects. Studies tend to focus on the amount of time spent watching television or using other types of electronics with screens (ie, computers, tablets, phones) with limited information on objectively measured sedentary time.[13,14] To our knowledge, no study has investigated how objectively measured estimates of children's MVPA and sedentary time relate to household income

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across countries of varying levels of HDI. Thus, the purpose of this study was to determine if children's objectively measured time in MVPA and sedentary time vary across levels of household income in countries at lower, middle, and higher levels of HDI, in accordance with the theory of epidemiological transition. It was hypothesized that objectively measured time in MVPA decreases linearly across income levels at the estimated 10th percentile of HDI but increases linearly across income levels at the 90th percentile of HDI. It was also hypothesized that a similar but reverse relationship exists for objectively measured sedentary time.

Methods

Study Design and Participants

The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) was a multinational cross-sectional study that collected objectively measured physical activity and sedentary time data on children from urban/suburban study sites in 12 countries. The study sites included cities in Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, the United Kingdom, and the United States. The 12 sites included in ISCOLE were in countries ranging from low (0.509, Kenya) to very high (0.929, Australia) HDI at the time of data collection.[15] We previously reported specific HDI for each country involved in ISCOLE.[6] Detailed information about the design, standardized methods, and accelerometry procedures used in ISCOLE has been previously published, including open access publication of a detailed manual of operations.[16,17] For this reason, only those procedures directly related to this study are presented here.

The institutional review board at the Pennington Biomedical Research Center (coordinating center) approved the overarching ISCOLE protocol, and approval was also obtained for each participating institution from their respective institutional/ethical review boards. Written informed consent was obtained from parents or legal guardians, and written child assent was also obtained as required by local institutional/ethical review boards before participation in the study.

Each study site was responsible for recruiting at least 500 children. The primary sampling frame was schools, which were typically stratified by an indicator of SES to maximize variability within sites.[16] The total number of participating schools was 256, with a range of 6 to 29 per country (median = 23.5 schools). From the initial sample of 7372 participants, 31 were excluded because they did not have body mass index data and a further 793 participants did not have valid accelerometer data (described later). The final analytical sample consisted of 6548 children aged 9–11 years (55% girls). Data were collected between September 2011 and December 2013 when children were attending school and excluded major holidays.

Procedures

As part of the standardized and rigorous ISCOLE protocol, the same instruments and data collection procedures were used in all sites. All research staff attended a training session and passed a certification test to be able to collect data.

Physical Activity and Sedentary Time. Children were asked to wear an ActiGraph GT3X+ accelerometer (ActiGraph LLC, Pensacola, FL) 24 hours per day for at least 7 consecutive days (removing only for water-related activities) attached to an elasticized belt and worn at the waist positioned at the right midaxillary line. Data were collected at a sampling frequency of 80 Hz and subsequently downloaded using ActiLife software (version 5.64 or later; ActiGraph LLC) with the low-frequency extension filter enabled. Because the accelerometer was worn for 24 hours per day, it was necessary to identify nocturnal sleep episode time distinct from waking nonwear time, and this was done using a 60-second epoch and published automated algorithms.[18,19] After exclusion of the nocturnal sleep episode time, nonwear time was determined as any sequence of at least 20 consecutive minutes of zero activity counts.[20] Once nocturnal sleep episode time and nonwear time were computed, Evenson et al[21] cut points were used to determine time (min/d) spent in MVPA (≥574 counts/15 s) and sedentary time (min/d; <25 counts/15 s). Children were only included in this analysis if they had ≥4 days of monitoring with at least 10 hours per day of waking wear time, including at least 1 weekend day.[22]

Household Income. Parents/guardians completed a questionnaire that included household income levels in a single question offering 8 to 10 country-specific response categories locally determined by each site. Income values were chosen to reflect the local economic conditions of each country. For analysis, the multiple household income categories that varied among countries were collapsed into 4 ranked levels that approximated quartiles and ensured the most balanced distribution possible within each country, and the successively higher levels (1 through 4) represent successively higher family income. The values of each income level have been previously published.[6]

Country HDI. Consistent with our previous publication,[6] values for the 2011 HDI[15] corresponding to estimated 10th, 50th, and 90th percentiles within the ISCOLE sample were chosen to represent lower, middle, and higher levels of human development. Percentiles were calculated based on weighted averages. The use of sample-based percentiles ensured that the results were not extrapolated beyond the sample HDI range and also reduced the likelihood of results being interpreted to correspond to specific countries in the sample.

Treatment of Missing Data

Overall, 668 participants (11%) were missing household income data. Four sites had missing household income data in excess of 10%: United Kingdom (15%), Brazil (21%), Portugal (21%), and South Africa (30%). Participants' missing household income data were not significantly different to those with complete household income data with respect to sex, age, obesity, MVPA, and sedentary time.

Consistent with our previous research,[6,23] missing values for household income were analyzed as multiply imputed data to reduce the chance of bias due to exclusion of these cases. Missing values were multiply imputed (5 imputations) using fully conditional specification methods, under missing at random assumptions[24] and using SAS software (version 9.4; PROC MI, SAS Institute Inc., Cary, NC). Country-specific models were used to impute household income categories, which were subsequently collapsed into the 4 household income levels, as previously described.

Statistical Analysis

Data analysis was conducted in 2017 to appropriately account for the multiply imputed household income data; results from all statistical analyses were averaged across the 5 imputed data sets, and the SEs were adjusted using the MIANALYZE procedure in SAS.

To assess the time spent in MVPA and sedentary time among the different levels of household income, we used multilevel random effects models (PROC MIXED) that accounted for clustering at both the school and country levels. Denominator degrees of freedom for statistical tests pertaining to fixed effects were calculated using the Kenward and Roger[25] approximation. The country-specific HDI and the country-specific sample household income levels have been published elsewhere.[6] For presentation, least-square means for MVPA and sedentary time were estimated separately for boys and girls at values corresponding to the previously mentioned HDI percentiles. Data are presented separately due to significant differences observed between boys and girls for both MVPA and sedentary time (data not shown).

Results

Descriptive characteristics of the sample are presented in Table 1. The estimated least-square means for time in MVPA and sedentary time for the 4 income levels at the 3 different HDI percentiles are shown in Figures 1–2 and Supplementary Table S1 and S2. Values are presented as least-square mean estimates (SE) in minutes per day. For boys, MVPA was negatively associated with income at the 10th percentile of HDI, with a difference of 16 minutes per day ($P < .001$) between level 1 and level 4 incomes. Although MVPA at income level 1 was lower than the other levels at the 50th percentile of HDI, there was a significant negative relationship at the 50th percentile of HDI with a difference of 3 minutes per day ($P < .002$) between level 2 and level 4 incomes. There was no significant relationship between income level and MVPA at the 90th percentile of HDI ($P = .15$). There was a significant positive relationship between income and boys' sedentary time only at the 10th percentile of HDI ($P = .03$). Sedentary time was 480 (15) minutes per day at income level 1 and 503 (15) minutes per day at income level 4. No significant associations were found between income and sedentary time at the 50th and 90th percentiles of HDI.

For girls, MVPA was also negatively associated with income level at the 10th and 50th percentiles of HDI (with a difference between income levels of 10 and 3 min/d, respectively; all $P < .01$). At the 90th percentile of HDI, a significant positive association between MVPA and income was observed, with a difference of 4 minutes per day ($P = .04$) between the highest and lowest income levels. No significant associations were found between income and sedentary time for girls.

Discussion

The results of this study demonstrated that the relationship of physical activity with income varies across countries that differ in level of human development. By contrast, sedentary time was mostly unrelated to income. At 10th and 50th percentile levels of HDI, children in households with lower income levels were more active than children in households with higher income levels. In girls, those in households with higher income from countries in the 90th percentile of HDI were less active than girls in households with lower income; however, this difference was not present for boys in countries at the 90th percentile of HDI. These results point to the possibility of an epidemiological transition in physical activity, displaying lower levels of MVPA at opposite ends of the income spectrum depending on the country's HDI level, especially for girls; however, this was not true for sedentary time. The meaning of these findings can affect the development of multicountry physical activity interventions because the targeted at-risk population may differ based on the country's HDI level.

It is difficult to place these results into the context of the existing literature because no other published studies have examined the income–HDI relationship with MVPA and sedentary time in a diverse multicountry sample of children and with such rigorous and standardized methodology. However, small-scale studies have been conducted in some of the countries included in this sample and similar results were found.[26] Difficulties also exist in determining which aspects of household income or the country's HDI specifically influence the amount of time that children spend in these specific behaviors. It is possible that the differences found in this study arise from a different mix of obligatory and discretionary physical activities. For example, in some sites, physical education class was mandated by the government, whereas in others, it was a decision at the school level. Furthermore, it is possible that income can influence active transportation, access to parks, other

Table 1 Descriptive Characteristics of ISCOLE Participants Stratified by Sex and Study Site (N = 6548)

	n		Age, y		MVPA		Sedentary time	
Country (site)	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
Australia (Adelaide)	225	266	10.4 (0.5)	10.3 (0.6)	75 (24)	57 (19)	471 (64)	482 (56)
Brazil (São Paulo)	242	252	10.0 (0.5)	10.0 (0.5)	71 (28)	48 (18)	492 (70)	507 (67)
Canada (Ottawa)	217	306	10.1 (0.4)	10.0 (0.4)	67 (19)	53 (17)	507 (66)	514 (61)
China (Tianjin)	261	240	9.4 (0.5)	9.4 (0.5)	50 (16)	41 (14)	552 (65)	579 (68)
Colombia (Bogotá)	422	435	10.0 (0.6)	10.0 (0.7)	76 (26)	60 (21)	491 (67)	509 (66)
Finland (Helsinki, Espoo, and Vantaa)	235	269	10.0 (0.5)	10.0 (0.4)	81 (28)	62 (21)	525 (71)	534 (64)
India (Bangalore)	254	299	10.0 (0.6)	10.0 (0.6)	62 (21)	38 (14)	489 (62)	539 (62)
Kenya (Nairobi)	233	269	9.7 (0.7)	9.8 (0.7)	81 (31)	64 (30)	486 (69)	502 (62)
Portugal (Porto)	305	381	10.0 (0.2)	10.0 (0.3)	68 (23)	47 (15)	537 (65)	563 (57)
South Africa (Cape Town)	184	284	9.9 (0.7)	9.7 (0.7)	75 (27)	59 (23)	480 (69)	491 (62)
United Kingdom (Bath and NE Somerset)	211	267	10.4 (0.5)	10.4 (0.5)	73 (24)	56 (18)	496 (62)	497 (58)
United States (Baton Rouge)	203	288	9.6 (0.7)	9.4 (0.6)	58 (20)	44 (16)	512 (62)	528 (61)

Abbreviations: ISCOLE, International Study of Childhood Obesity, Lifestyle, and the Environment; MVPA, moderate to vigorous physical activity.

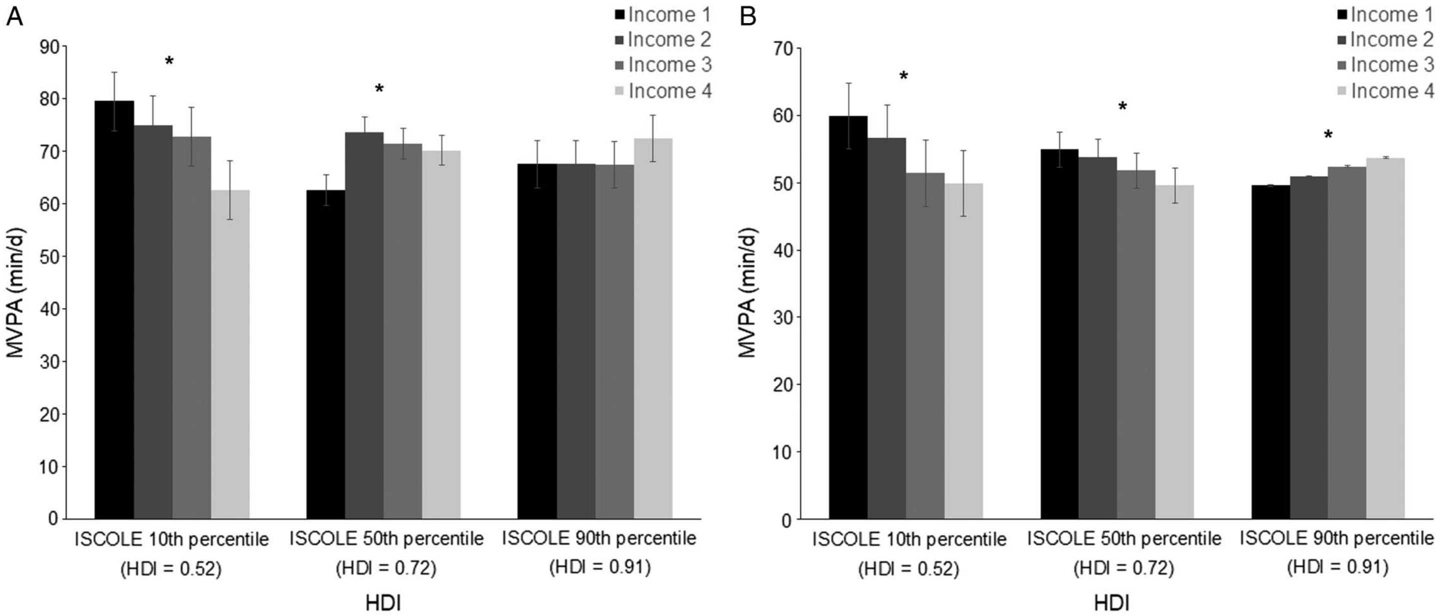

Figure 1 — Income gradients in MVPA across HDI levels for (A) boys and (B) girls. Data are shown as least-square means at HDI levels corresponding to the 10th, 50th, and 90th percentiles of the ISCOLE sample (HDI = 0.52, 0.72, and 0.91, respectively). Tests for linear trend are indicated: *$P < .05$. HDI indicates Human Development Index; MVPA, moderate to vigorous physical activity; ISCOLE, International Study of Childhood Obesity, Lifestyle, and the Environment.

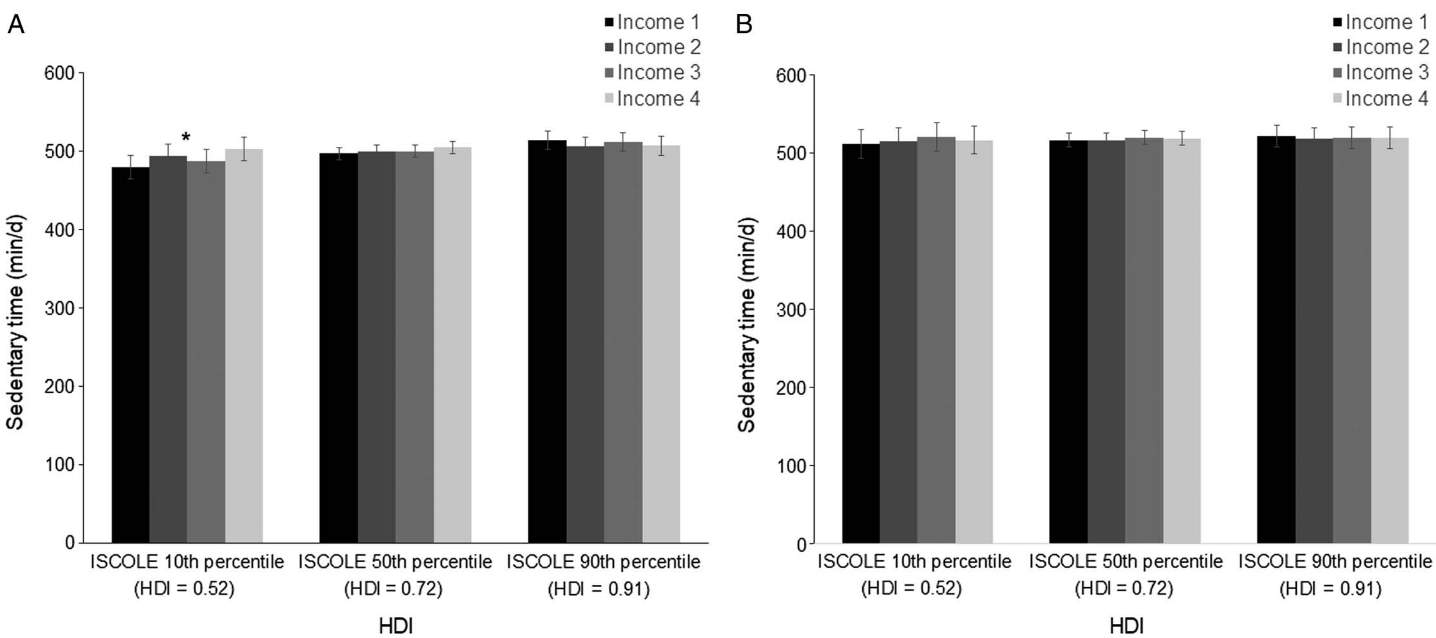

Figure 2 — Income gradients in sedentary time across HDI levels for (A) boys and (B) girls. Data are shown as least-square means at HDI levels corresponding to the 10th, 50th, and 90th percentiles of the ISCOLE sample (HDI = 0.52, 0.72, and 0.91, respectively). Tests for linear trend are indicated: *$P < .05$. HDI indicates Human Development Index; ISCOLE, International Study of Childhood Obesity, Lifestyle, and the Environment.

recreational activities, sports participation, and the overall view of physical activity as positive for children; however, this speculation could not be tested using our data.

For adults in a single-country study, it has been suggested that technological advances associated with economic development in labor and housekeeping have led to decreases in energy expenditure associated with physical activity.[2] In a multicountry adult study,[11] there were variations in MVPA levels between the countries with different HDI levels without a clear association between MVPA and HDI levels. In addition, in the individual countries, different aspects of SES were significantly related to MVPA levels, making it challenging to generalize. However, in the same study,[11] the only factor that produced a similar influence across all 5 countries was car ownership, where adult car owners were less active than those who did not own cars. This suggests that access to transportation might play a role in explaining physical activity levels among adults; however, the implications for children are not known.

The application of the theory of epidemiological transition to factors[4] other than patterns of morbidity and mortality changes is relatively new but has been successfully explored to demonstrate changes in nutrition and obesity.[27,28] We have shown results in our cross-sectional sample that support the possibility of epidemiological transition for obesity.[6] Likewise, when we analyzed methods and time of active transport, we showed a general distribution according to active school transport for trips of less than 5 minutes by country income level, which in turn could be associated with the physical activity epidemiological transition.[29] In this study, we present an extension of those findings, creating a clearer picture of the physical activity transition that is more focused on MPVA changes.[30] There are multiple factors that can be contributing to the observed results, including negative changes to the built environment that may occur as countries undergo economic development.

This study had numerous strengths, such as the economic and social diversity of site locations across the world as well as widely accepted standardized methodology and equipment utilized in each site. However, this study was not without limitations. The samples were mostly limited to 1 city in each country, which were not randomly chosen for global representation. In addition, the sample was drawn primarily from urban and suburban settings, and because we used country-level HDI values and sample-specific income levels, results may not generalize to rural settings. Despite this, the sampling was carried out in such a manner as to maximize variability in income in each site. We chose to focus on children with a mean age of 10 years, as this age corresponds to the minimum age where children can complete their own questionnaires, and it also avoids the pubertal period where dramatic changes in body composition occur. Parental/guardian-reported annual household income was used as a proxy of SES and did not include other facets that can be used to define SES. A limitation is the lack of data on household income for 11% of the sample; however, we used the widely validated multiple imputation method to overcome this limitation. We utilized estimates of MVPA and sedentary time for different HDI levels (10th, 50th, and 90th percentiles) of the sample, not at an actual country-specific HDI. Although the ActiGraph has been used for measurement of both MVPA and sedentary time, there is much more evidence of its validity for MVPA measurement[21,31,32] and some research has indicated that it is not as accurate as the ActivPAL to measure sedentary behavior[33] as defined by the Sedentary Behaviour Research Network.[34,35] This could be one of the reasons for the lack of relationship between sedentary time and income at different HDI levels. We used accelerometers to objectively measure physical activity; however, we did not collect information on knowledge, attitudes, and practices toward physical activity and the most common types of physical activity engaged in, which all could be impacted by the shifts in economy.

Conclusions

In this extension of our previous findings,[6,23] we showed that the relationship between MVPA and household income is variable across different countries' HDI levels and sex, and this is consistent with the theory of epidemiologic transition.[1] By contrast, sedentary time was mostly unrelated to household income as indicated by parent-reported household income. Additional studies, especially longitudinal surveillance studies, are necessary to confirm these findings. This information is important for the development of multicountry physical activity/sedentary time interventions in children. It indicated that country's HDI, family income, and sex should be taken into consideration. For example, children of low household income might be targeted in countries with higher HDI, whereas children of high household income might be targeted at lower HDI countries. These results could also serve as an alert to promote action before unintended consequences of development negatively affect physical activity and sedentary time in those countries undergoing early stages of economic transition.

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