OPEN

Levels and Correlates of Objectively Measured Sedentary Behavior in Young Children: SUNRISE Study Results from 19 Countries

KATHARINA E. KARIIPPANON[1], KAR HAU CHONG[1], XANNE JANSSEN[2], SIMONE A. TOMAZ[3], EVELYN H. C. RIBEIRO[4], NYARADZAI MUNAMBAH[5], CECILIA H. S. CHAN[6], PW PRASAD CHATHURANGANA[7], CATHERINE E. DRAPER[8], ASMAA EL HAMDOUCHI[9], ALEX A. FLORINDO[4], HONGYAN GUAN[10], AMY S. HA[6], MOHAMMAD SOROWAR HOSSAIN[11], DONG HOON KIM[12], THANH VAN KIM[13], DENISE C. L. KOH[14], MARIE LÖF[15], BANG NGUYEN PHAM[16], BEE KOON POH[17], JOHN J. REILLY[2], AMANDA E. STAIANO[18], ADANG SUHERMAN[19], CHIAKI TANAKA[20], HONG KIM TANG[13], MARK S. TREMBLAY[21], E. KIPLING WEBSTER[22], V. PUJITHA WICKRAMASINGHE[7], JYH EIIN WONG[17], and ANTHONY D. OKELY[1]

[1]Early Start, School of Health and Society, Faculty of the Arts, Social Science and Humanities, University of Wollongong, NSW, AUSTRALIA; [2]Physical Activity for Health Group, School of Psychological Sciences and Health, University of Strathclyde, Glasgow, Scotland, UNITED KINGDOM; [3]College of Medical, Veterinary and Life Sciences, University of Glasgow, Scotland, UNITED KINGDOM; [4]Universidade de São Paulo, São Paulo, BRAZIL; [5]Rehabilitation Unit, Faculty of Medicine and Health Sciences, University of Zimbabwe, Harare, ZIMBABWE; [6]Faculty of Education, The Chinese University of Hong Kong, Hong Kong, THE PEOPLE'S REPUBLIC OF CHINA; [7]Department of Paediatrics, Faculty of Medicine, University of Colombo, Colombo, SRI LANKA; [8]SAMRC/Wits Developmental Pathways for Health Research Unit, University of the Witwatersrand, Johannesburg, SOUTH AFRICA; [9]Unité Mixte de Recherche Nutrition et Alimentation, CNESTEN-Université Ibn Tofail URAC 39, Regional Designated Center of Nutrition Associated with AFRA/IAEA, Rabat, MOROCCO; [10]Department of Early Childhood Development, Beijing Municipal Key Laboratory of Child Development and Nutriomics, Capital Institute of Pediatrics, Beijing, CHINA; [11]Biomedical Research Foundation, Dhaka, BANGLADESH; [12]Korea Institute of Child Care and Education, Seoul, REPUBLIC OF KOREA; [13]Department of Epidemiology, Faculty of Public Health, Pham Ngoc Thach University of Medicine, Ho Chi Minh City, VIETNAM; [14]Centre of Community Education and Well-being, Faculty of Education, Universiti Kebangsaan Malaysia, Kuala Lumpur, MALAYSIA; [15]Department of Health, Medicine and Caring Sciences, Linköping University, Linköping, SWEDEN; [16]Papua New Guinea Institute of Medical Research, Goroka, PAPUA NEW GUINEA; [17]Centre for Community Health Studies (ReaCH), Faculty of Health Sciences, Universiti Kebangsaan Malaysia, Kuala Lumpur, MALAYSIA; [18]Pennington Biomedical Research Center, Baton Rouge, LA; [19]Faculty of Sport and Health Education, Universitas Pendidikan Indonesia, Bandung, INDONESIA; [20]Department of Human Nutrition, Tokyo Kasei Gakuin University, Tokyo, JAPAN; [21]Healthy Active Lifestyle and Obesity (HALO) Research Group, Children's Hospital of Eastern Ontario Research Institute, Ottawa, CANADA; and [22]Institute of Public and Preventive Health, Augusta University, Augusta, GA

EPIDEMIOLOGY

ABSTRACT

KARIIPPANON, K. E., K. H. CHONG, X. JANSSEN, S. A. TOMAZ, E. H. C. RIBEIRO, N. MUNAMBAH, C. H. S. CHAN, P. P. CHATHURANGANA, C. E. DRAPER, A. EL HAMDOUCHI, A. A. FLORINDO, H. GUAN, A. S. HA, M. S. HOSSAIN, D. H. KIM, T. VAN KIM, D. C. L. KOH, M. LÖF, B. N. PHAM, B. K. POH, J. J. REILLY, A. E. STAIANO, A. SUHERMAN, C. TANAKA, H. K. TANG, M. S. TREMBLAY, E. K. WEBSTER, V. P. WICKRAMASINGHE, J. E. WONG, AND A. D. OKELY. Levels and Correlates of Objectively Measured Sedentary Behavior in Young Children: SUNRISE Study Results from 19 Countries. *Med. Sci. Sports Exerc.*, Vol. 54, No. 7, pp. 1123–1130, 2022. **Purpose:** There is a paucity of global data on sedentary behavior during early childhood. The purpose of this study was to examine how device-measured sedentary behavior in young children differed across geographically, economically, and

Address for correspondence: Katharina E. Kariippanon, Ph.D., University of Wollongong, Bldg. 21.214, Northfields Ave, Gwynneville, NSW 2522, Australia; E-mail: kathar@uow.edu.au.
Submitted for publication September 2021.
Accepted for publication January 2022.

0195-9131/22/5407-1123/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0000000000002886

sociodemographically diverse populations, in an international sample. **Methods:** This multinational, cross-sectional study included data from 1071 children 3–5 yr old from 19 countries, collected between 2018 and 2020 (pre-COVID). Sedentary behavior was measured for three consecutive days using activPAL accelerometers. Sedentary time, sedentary fragmentation, and seated transport duration were calculated. Linear mixed models were used to examine the differences in sedentary behavior variables between sex, country-level income groups, urban/rural settings, and population density. **Results:** Children spent 56% (7.4 h) of their waking time sedentary. The longest average bout duration was 81.1 ± 45.4 min, and an average of 61.1 ± 50.1 min·d^{-1} was spent in seated transport. Children from upper-middle–income and high-income countries spent a greater proportion of the day sedentary, accrued more sedentary bouts, had shorter breaks between sedentary bouts, and spent significantly more time in seated transport, compared with children from low-income and lower-middle–income countries. Sex and urban/rural residential setting were not associated with any outcomes. Higher population density was associated with several higher sedentary behavior measures. **Conclusions:** These data advance our understanding of young children's sedentary behavior patterns globally. Country income levels and population density appear to be stronger drivers of the observed differences, than sex or rural/urban residential setting.
Key Words: SITTING, EARLY YEARS, SOCIODEMOGRAPHIC CHARACTERISTICS, ACCELEROMETRY

EPIDEMIOLOGY

Sedentary behavior is recognized as an important risk factor associated with adverse health outcomes in adults (1). Although evidence on the health and developmental implications of sedentary behavior in the early years is inconclusive (2), research suggests an unfavorable association between sedentary behavior and adiposity, bone mineral content, psychological health, and cognitive development in children under the age of 4 yr (3). Further, a dose–response relationship between increased sedentary time and poor health outcomes has been observed in school-age children and youth (4). Considering that sedentary behavior tracks from early-to-middle childhood at moderate-to-large levels (5), there is a need to investigate sedentary behavior patterns and correlates in young children.

A recent systematic review examining correlates of sedentary time in young children was unable to identify any consistent correlates, suggesting that further investigation is needed (6). However, there is some evidence to suggest associations between sex and sedentary behavior, with girls typically more sedentary than boys (7). Both device-measured (8) and self-reported (9) cross-sectional data indicate that rural children are less sedentary than children residing in urban areas. Studies assessing associations between urban population density and sedentary behavior have shown that older children residing in higher-density urban locations spend significantly more time in sedentary behaviors compared with those in lower-density areas (10).

European (11) and international (12) multicountry device-measured sedentary behavior data from high-income countries (HIC) suggest that there are substantial differences in 3- to 5-yr-old children's sedentary time. However, limited data are available among young children, particularly from low- and middle-income countries, many of which are experiencing rapid urbanization (13). A recent systematic review of 50 studies reporting device-measured sedentary behavior prevalence data among 2- to 5-yr-olds found only one study conducted in an upper-middle–income country (UMIC) and none from low- or lower-middle–income countries (LLMIC), with the remaining 49 studies from HIC (7). This highlights a notable gap in our understanding of how sedentary behavior patterns may differ across geographically, culturally, and economically diverse populations. The dearth of evidence is concerning given that sedentary behavior is now considered a major public health problem (14), the mounting evidence on the all-cause mortality associated with sitting time (15), and the parallel concerns about the considerable contribution of physical inactivity to the global disease burden, 75% of which is borne by LLMIC and UMIC (16). Recent increases in sedentary behavior and reduced time spent in outside play, attributable to COVID-19 restrictions, among a global sample of young children (17), underscores the need to increase our understanding and generate capacity to respond.

The 2019 *Guidelines on Physical Activity, Sedentary Behaviour and Sleep for Children Under 5 Years of Age* by WHO provides further impetus to investigate sedentary behavior in this age-group (18). Although falling short of setting a definitive limit on daily sedentary time, the WHO guidelines recommend that 3- and 4-yr-olds should not be restrained for more than 1 h at a time (e.g., in prams/strollers) or sit for extended periods. In addition, sedentary screen time should be limited to no more than 1 h·d^{-1}, with less considered better. It is noteworthy that the evidence underpinning the WHO guidelines is almost exclusively based on studies from HIC, further emphasizing the need for more internationally diverse data that examine the contextual differences of sedentary behavior patterns across populations (19).

The aim of this study was to investigate accelerometer-derived sedentary behavior patterns in a geographically, economically, and culturally diverse international sample of 3- to 5-yr-olds (referred to as "young children" from here on) and to examine associations with multiple multilevel sociodemographic variables, including sex, residential setting, population density, and country income classification.

METHODS

Study Setting and Recruitment

Data used in this study were a subset of the SUNRISE pilot study sample (20), an international cross-sectional study of movement behaviors and associated health and developmental outcomes in the early years. Recruitment occurred using convenience cluster sampling through either early childhood education or care services or from the community, at a village level. Children were eligible to participate if they were 3–5 yr of age and typically developing. Data were collected from a sex-balanced sample of up to 100 children, with half typically recruited from urban and rural settings in 19 countries. This sample size has been deemed sufficient to pilot the protocol in each setting.

Ethical approval was obtained from the University of Wollongong, Australia (ref. no. 2018/044) and the appropriate ethics committee(s) in each country. Data collection occurred between March 2018 and March 2020. Written informed consent was obtained from all caregivers.

Measures and Procedures

Sedentary behavior. Sedentary time was measured using the activPAL triaxial inclinometer (PAL Technology Ltd., Glasgow, Scotland), suitable for use among young children (21). Worn on the right thigh and held in place with surgical tape, it provides time-stamped data collected at a sampling frequency of 10 Hz. Each child wore the activPAL continuously for three consecutive days (24 h·d^{-1}), including during water activities and sleeping, to allow for an accurate estimate of habitual movement behavior (22,23).

Raw data were processed with the activPAL proprietary algorithms via PALbatch software (v8.10.12; PAL Technologies Ltd., Glasgow, Scotland). Two event files (per child) were generated for the analysis. The first was created using the Standard PAL Analysis Algorithm (VANE), which classifies activity events into three main categories (sitting/lying, standing, stepping) based on the thigh position and dynamic acceleration information. The second was created using the Enhanced Analysis Algorithm (CREA), which quantifies periods of non–wear time (based on a measure of stillness, using a 60-min cutoff) and seated transport (based on the presence of dynamic components in the acceleration signals from a sitting event). Although the validity remains unclear, these algorithms have been used in other studies. Little evidence is currently available regarding the validity of these algorithms for this age-group, they are being used in similar research (24), and validation in youth and adults is promising (25).

Visual file inspection identified children with at least 1 d of 24 h data. The VANE event files were then analyzed using a custom-made MATLAB program (Sedentariness). Waking hours on each wear day were identified using the built-in algorithm that detects sleep offset and onset times. To avoid misclassification of sedentary behavior as nocturnal sleep, only the days with at least 8 h of waking wear time were considered valid and included in the final analyses. This may have included periods of napping.

Output variables included total time spent sitting or lying, percentage of waking hours spent in sedentary activities, number of bouts lasting >1 min, and the durations of the longest sedentary bout and break. Further, the amount of time children spent in seated transport and whether >60 consecutive minutes were spent on seated transport were calculated. All variables were calculated for each day and then averaged across all valid days for each child for the final analyses. Children with any non–wear time were excluded from the analysis.

Demographics. Demographic data were collected via primary caregiver report in local language as per the SUNRISE protocol (26). Caregivers completed a questionnaire or participated in a face-to-face or telephone interview, particularly if literacy was a barrier to self-report. Demographic variables included age, sex, and residential setting (urban/rural). Because of the absence of an internationally harmonized definition of degree of urbanization (27), locally relevant criteria (e.g., distance from town, service availability, and population density) were used to classify settings as urban or rural. The World Bank's country income level classifications were used to categorize countries as LLMIC, UMIC, or HIC (20). These variables served both a descriptive purpose and were utilized as exposure variables in the analysis of the correlates of sedentary behavior patterns. The population density of the study sites (early childhood education/care or village) was determined according to authoritative local sources. As population density was not normally distributed, the following categories were used to balance participant numbers for statistical purposes: (i) ≤999, (ii) 1000–4999, (iii) 5000–7499, and (iv) ≥7500 population per square kilometer.

Statistical Analysis

Data were pooled from all countries. Linear mixed models were used to assess differences in the continuous measures of sedentary behavior between (i) boys and girls, (ii) countries' income levels, (iii) residential setting, and (iv) population density categories. Similar analyses were conducted on the dichotomous variables using generalized linear mixed models. All models were adjusted for childcare centers/villages and country sites as random effects and child's age and sex (except for the sex-specific models) as covariates.

RESULTS

Data were drawn from SUNRISE pilot study sites in Australia, Bangladesh, Brazil, Canada, China, Hong Kong, Indonesia, Japan, Korea Republic, Malaysia, Morocco, Papua New Guinea, Scotland, South Africa, Sri Lanka, Sweden, United States, Vietnam, and Zimbabwe. Of the 1207 participating children, 1071 (89%) provided valid accelerometry data for the present analyses. The mean number of valid days was 2.4. Of the sample, 10% had one valid day, 43% had two valid days, and 46.3% had three valid days. There were eight reports of minor skin irritation in Canada, Bangladesh, and Australia after using activPAL. See Table 1 for difference in descriptive characteristics between the analytical and the excluded sample.

Children spent 56.1% of their daily waking hours (mean = 13.2 ± 1.6 h·d^{-1}) sedentary, equating to 7.4 h·d^{-1}

TABLE 1. Descriptive characteristics of the analytic sample.

	Analytic Sample (n = 1071)		Excluded Sample (n = 136)		
	n	Pct.	n	Pct.	P Value for Comparison
Age, mean ± SD, yr[a]	4.5 ± 0.5		4.5 ± 0.5		0.56
Sex (boys)[b]	553	51.6	64	47.1	0.32
Country income level[b]					
LLMIC	321	30	42	30.9	<0.001
UMIC	358	33.4	66	48.5	
HIC	392	36.6	28	20.6	
Residential areas[b]					
Urban	537	50.1	82	60.3	0.026
Rural	534	49.9	54	39.7	

[a]Differences between analytic sample and excluded sample were examined using independent samples t-test.
[b]Differences between analytic sample and excluded sample were examined using chi-square test.

EPIDEMIOLOGY

TABLE 2. Accelerometer-measured daily sedentary behavior patterns, grouped by boys and girls.

	All (n = 1071)	Boys (n = 553)	Girls (n = 518)	P Value[a]
Sedentary time (min·d^{-1})	444.9 ± 101.4	447.4 ± 106.4	442.2 ± 95.8	0.39
Sedentary time (%·d^{-1})	56.1 ± 10.5	56.5 ± 11.1	55.8 ± 9.7	0.24
Bouts >1 min	68.0 ± 16.9	67.6 ± 18.0	68.3 ± 15.7	0.52
Longest sedentary bout (min)	81.1 ± 45.4	82.9 ± 48.0	79.2 ± 42.4	0.39
Longest break bout (min)	25.7 ± 17.2	25.6 ± 19.7	25.8 ± 14.2	0.94
Total time spent in seated transport (min·d^{-1})[b]	61.1 ± 50.1	62.1 ± 51.6	60.0 ± 48.4	0.17
Spent >60 continuous minutes per day on seated transport, n (%)[c]	251 (23.4)	133 (24.1)	118 (22.8)	0.37

Data are presented as mean ± SD unless otherwise indicated.
[a]Differences between groups (boys vs girls) were tested using linear mixed models, adjusted for clustering effects (country sites and childcare center as random effects).
[b]Analytic sample, n = 1009 (522 boys, 487 girls). d refers to waking day.
[c]Reported as M of n and % in place of SD.

and accrued an average of 68 ± 16.9 sitting bouts of longer than 1 min duration. Children's longest sedentary bout lasted an average of 81.1 ± 45.5 min. The longest break between sedentary bouts lasted 25.7 ± 17.2 min on average. Children spent 61.1 ± 50.1 min·d^{-1} in seated transport and 23.4% of the sample spent >60 consecutive minutes per day in seated transport. No significant differences were observed between boys and girls for any of the sedentary behavior variables (see Table 2).

Table 3 reports sedentary behavior levels and patterns grouped by country income levels. Children from UMIC spent the greatest proportion of their day sedentary, which was significantly higher compared with children from LLMIC (mean difference [MD] = 6.3%). The longest overall sedentary bout among children from UMIC was significantly longer compared with both children from LLMIC (MD = 28.1 min) and HIC (MD = 26.1 min). The longest break between sedentary bouts was significantly shorter among children from HIC compared with children from LLMIC (MD = 6.2 min). Children from HIC also spent significantly more time in seated transport compared with children from LLMIC (MD = 39.4 min) and UMIC (MD = 33.9 min).

No significant differences were observed for any of the outcome variables between children from rural and urban residential settings (see Table 4). Population density within the study sites ranged from 12 people per square kilometer in Argyll and Bute, Scotland, to 41,000 people per square kilometer in Dhaka, Bangladesh. Figure 1 illustrates sedentary behavior patterns by four population density groupings. As population density increased, from lower density (≤999·km^{-2}) to higher density (>5000·km^{-2}), significant increases (all P = <0.0001) in multiple sedentary behavior variables were noted, including the total time and proportion of the day spent sedentary, the duration of the longest sedentary bout, and the total time spent in seated transport (see Table 5).

TABLE 3. Sedentary behavior levels and patterns, grouped by country income levels.

	LLMIC (n = 321)	UMIC (n = 358)	HIC (n = 392)	P Value
Sedentary time (min·d^{-1})[c]	397.3 ± 102.9[a]	468.8 ± 97.1[b]	462.1 ± 90.5[b]	<0.001
Sedentary time (%·d^{-1})[c]	52.0 ± 12.0[a]	58.3 ± 9.8[b]	57.5 ± 8.5[a,b]	0.002
Bouts >1 min (n·d^{-1})[c]	66.4 ± 17.7	65.1 ± 15.9	71.9 ± 16.6	0.046
Longest sedentary bout (min·d^{-1})[c]	71.0 ± 52.2[a]	99.1 ± 41.9[b]	73.0 ± 37.0[a]	<0.001
Longest break bout (min·d^{-1})[c]	28.4 ± 20.8[a]	27.2 ± 18.3[a,b]	22.2 ± 11.5[b]	0.006
Total time spent in seated transport (min·d^{-1})[c]	44.8 ± 43.8[a]	50.3 ± 41.6[a]	84.2 ± 53.5[b]	<0.001
Spent >60 continuous minutes per day on seated transport, n (%)[c,d]	43 (13.4)	54 (15.1)	154 (39.3)	0.29

Data are presented as mean ± SD unless otherwise indicated.
[a,b]Mean values with different superscript letters are significantly different from each other (P < 0.05).
[c]Differences between groups were tested using linear mixed models or generalized linear mixed models, adjusted for child's age, sex, and clustering effects (childcare centers/villages and country sites as random effects). d refers to waking day.
[d]Reported as M of n and % in place of SD.

TABLE 4. Sedentary behavior levels and patterns, grouped by residential setting.

	Urban (n = 537) Mean SD	Rural (n = 534) Mean SD	P Value
Sedentary time (min·d^{-1})[a]	446.5 ± 101.1	443.3 ± 101.8	0.70
Sedentary time (%·d^{-1})[a]	57.0 ± 10.5	55.3 ± 10.4	0.40
Bouts >1 min (n·d^{-1})[a]	66.8 ± 16.3	69.2 ± 17.5	0.18
Longest sedentary bout (min·d^{-1})[a]	84.4 ± 45.5	77.8 ± 45.1	0.98
Longest break bout (min·d^{-1})[a]	25.6 ± 15.9	25.9 ± 18.5	0.90
Total time spent in seated transport (min·d^{-1})[a]	68.4 ± 53.8	53.7 ± 44.9	0.18
Spent >60 continuous minutes per day on seated transport, n (%)[b,c]	155 (28.9)	96 (18)	0.91

Data are presented as mean ± SD unless otherwise indicated.
[a]Differences between groups were tested using linear mixed models, adjusted for child's age, sex, and clustering effects (childcare centers/villages and country sites as random effects); d refers to waking day.
[b]Differences between groups were tested using generalized linear mixed models, adjusted for child's age, sex, and clustering effects (childcare centers/villages and country sites as random effects); d refers to waking day.
[c]Reported as M of n and % in place of SD.

DISCUSSION

This is the first study to examine device-measured sedentary behavior among young children across a wide range of countries from LLMIC to HIC. Overall, children from UMIC and HIC spent a greater proportion of the day sedentary, accrued more sedentary bouts, had shorter breaks between sedentary bouts, and spent significantly more time in seated transport than children from LLMIC. Further, an increase in population density was associated with increases in multiple sedentary behavior measures, particularly the length of sedentary bouts and time spent in seated transport. Benchmarking sedentary behavior levels and patterns and examining sociodemographic differences in sedentary behavior is an important first step to provide insights on young children's sedentary behavior profiles and their alignment with elements of the sedentary behavior recommendations from the WHO guidelines.

In contrast to existing research undertaken from almost exclusively in HIC examining sex differences in device-measured sedentary behavior (7), we did not find that boys are less sedentary than girls in the early years. This is perhaps because of the inclusion of data from LLMIC and UMIC in our data set and highlights the need for caution when generalizing outcomes based on data from HIC.

A novel finding is the considerable differences in sedentary behavior levels and patterns between children from the "lower-middle" compared with the "upper-middle" income groups. Countries in these two distinct income categories are often grouped together as one "middle-income" group and are frequently also grouped with low-income countries. Our

EPIDEMIOLOGY

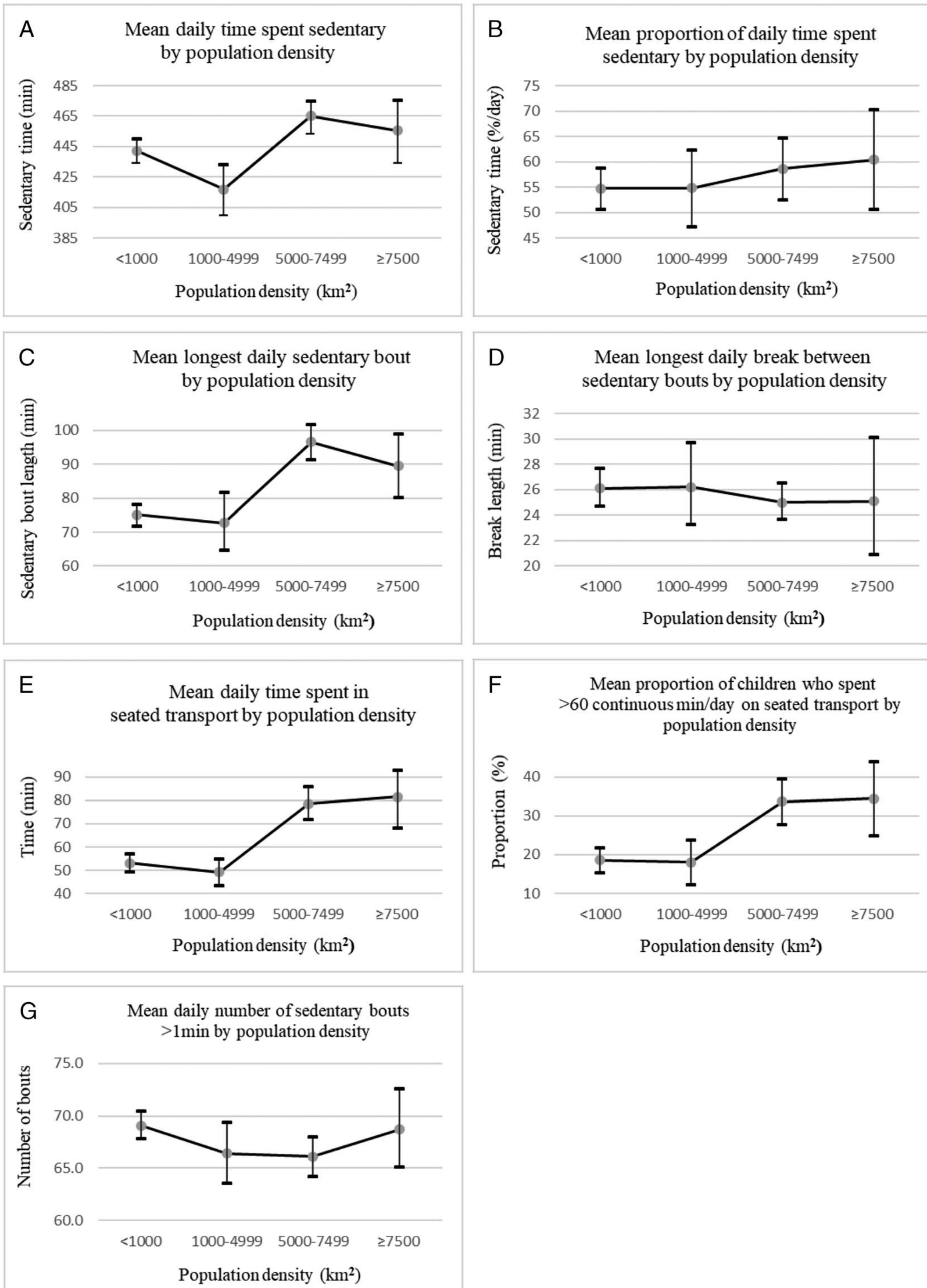

FIGURE 1—Sedentary behaviors by population density (per km^2). A–G, Report variations in seven sedentary behavior variables across four population density groupings.

findings show that sedentary behavior patterns of children from the UMIC category are much more similar to those of HIC children, suggesting that UMIC may be moving in the same direction as HIC in terms of sedentary behavior levels and patterns. This could be explained by the increased purchasing power in UMIC compared with LLMIC populations, which may result in the acquisition of products that encourage sedentary behavior, e.g., tablet/smart phone or motorized transport. Sedentary behavior may therefore be indirectly valued as an indicator of affluence and prestige and considered socially desirable. This epidemiologic transition has been identified in related fields of research, such as obesity, where it has been shown that in countries in transition, groups with higher incomes are the first to shift to a more sedentary

TABLE 5. Sedentary behavior levels and patterns, grouped by population density categories.

	Very Low < 1000·km^{-2} (n = 555)		Low 1000–4999·km^{-2} (n = 167)		Middle 5000–7499·km^{-2} (n = 253)		High ≥ 7500·km^{-2} (n = 96)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	P Value
Sedentary time (min·d^{-1})^{d}	442.3 ± 102.6^{a}		416.9 ± 107.2^{b}		465.1 ± 88.4^{c}		455.4 ± 104.9^{a,c}		<0.001
Sedentary time (%·d^{-1})^{d}	54.7 ± 10.8^{a}		54.8 ± 11.2^{a}		58.6 ± 8.3^{b}		60.4 ± 9.8^{b}		<0.001
Bouts >1 min (n·d^{-1})^{d}	69.1 ± 16.6		66.4 ± 18.9		66.1 ± 15.6		68.7 ± 18.3		0.07
Longest sedentary bout (min·d^{-1})^{d}	75.2 ± 40.0^{a}		72.7 ± 56.4^{a}		96.6 ± 43.0^{b}		89.5 ± 48.9^{b}		<0.001
Longest break bout (min·d^{-1})^{d}	26.1 ± 16.8		26.2 ± 21.1		25.0 ± 11.0		25.1 ± 24.2		0.78
Total time spent in seated transport (min·d^{-1})^{d}	53.1^{a} ± 45.0		49.3 ± 38.6^{a}		78.5 ± 54.4^{b}		81.4 ± 64.7^{b}		<0.001
Spent >60 continuous minutes per day on seated transport, n (%)^{e,f}	103 (18.6)		30 (18.0)		85 (33.6)		33 (34.4)		0.76

Data are presented as mean ± SD unless otherwise indicated.

[a,b,c]Mean values sharing the different superscript letters are significantly different from each other (P < 0.05).

[d]Differences between groups were tested using linear mixed models, adjusted for child's age, sex, and clustering effects (childcare centers/villages and country sites as random effects); d refers to waking day.

[e]Differences between groups were tested using generalized linear mixed models, adjusted for child's age, sex, and clustering effects (childcare centers/villages and country sites as random effects); d refers to waking day.

[f]Reported as M of n and % in place of SD.

EPIDEMIOLOGY

lifestyle before those of lower income (28). Research among adolescents in 68 LMIC has also reported that increases in a country's economic development were coupled with higher levels of sedentary behavior among both sexes (29). Our findings provide preliminary evidence of a potential sedentary behavior transition that appears to begin in early childhood. Research is needed to understand the factors that mediate the relationship between income levels and different types of children's sedentary behavior in the early years (30).

The considerable differences in sedentary behavior profiles between young children from LLMIC and UMIC found in our study would have gone unnoticed in aggregated data analysis. These findings have implications for public health interventions at the UMIC country level, which may not be receiving the required attention.

Our results showed no significant differences in sedentary behavior between urban and rural residential settings. Although this stands in contrast to a small number of existing studies examining within country differences, the local variation in criteria used to classify areas as rural or urban may explain this finding. When using urban density as a measure to classify a location on the urban–rural continuum for example, urban study sites from some countries (e.g., Ottawa, Canada) fell into a lower population density category compared with some rural study sites (e.g., Ciamis, Indonesia).

The population density analyses revealed a more consistent picture of associations with sedentary behavior than residential setting. Children from locations with a higher population density were found to spend a greater proportion of the day spent sedentary, accrued a longer duration of sedentary bouts, and spent more total time spent in seated transport, compared with those from lower-density areas. Studies assessing associations between urban population density and sedentary behavior have shown that older children residing in higher-density locations spend significantly more time in sedentary behaviors compared with those in lower-density residential areas (10). Questions arise around which factors are important in this context. Of particular interest are modifiable environmental mediators (e.g., safe outdoor play spaces) as these can bring about sustainable population level changes in behavior patterns (31). The International Society for Physical Activity and Health in their "Eight Investments That Work for Physical Activity" specify the need for "active urban design" and "active travel." They call for urban environments with more destinations within shorter distances, better opportunities for walking and cycling, and more urban green spaces (32). This is backed by research highlighting the relationship between urban design, transport, and health (33). Given the finite nature of waking time in any given 24-h period, we hypothesize that urban environments which foster physical activity in this way may result in reductions in sedentary behaviors (34).

The WHO guidelines recommend that young children should not be restrained for more than 60 min at a time (18). Our data show a clear trend suggesting that as country income increases, so does total time spent in seated transport. This is not unexpected given the greater access to personal vehicles in HIC and policies and enforcement around seatbelts and other child safety measure in vehicles. This finding is supported by research into the active transportation of children in emerging economies, which shows that children from poorer families and those who live closer to schools were also consistently more likely to engage in active transportation (35). This trend was further mirrored in our population density analysis, which showed that as population density rose above 5000 population per square kilometer, young children spent a significantly greater total time in seated transport. Although time spent in seated transport is only one element of what constitutes "restrained sitting," the high rates justify further investigation.

The WHO guidelines also recommend that children under 5 yr old should not sit for extended periods. Although there is currently no definition for what constitutes prolonged sitting in the early years, there is evidence showing the physiological (36) and cognitive (37) benefits of breaking up sitting periods in adult populations. Given that our data show that 39% of HIC children spent >60 min·d^{-1} in seated transport, it warrants further research in young children.

A strength of our study is the diverse sample that adds new understanding of sedentary behaviors among young children, particularly in low- and middle-income countries. The use of device-measured 24-h data using an inclinometer is a further strength. This is also the first study to our knowledge that examined associations between sedentary behavior patterns and country income levels in a global sample. However, despite the diversity of our study sample, a limitation is the relatively small, 3-d convenience sample of pilot data, which, coupled with the cross-sectional design, precludes causal inference. The inability to identify periods of daytime napping is an additional limitation. The lack of a consistent definition of what constitutes a rural and urban setting may be a further weakness. A limitation of device-measured sedentary behavior is that it is devoid of the context in which the sedentary behavior occurs. We know that not all sedentary behavior is equal (e.g., building a puzzle or reading while sedentary is not equal to sitting/lying watching television or restrained in a car seat), but we are not able to comment on or assess these more nuanced aspects of sedentary behavior.

CONCLUSIONS

Our investigation of levels and correlates of device-measured sedentary time in a diverse international sample of young children revealed that 56.1% of their daily waking hours were spent sedentary. Our results highlight how children residing in UMIC appear to be exhibiting similar unfavorable sedentary behavior profiles to children in HIC. Further, our study highlights significant associations between population density and sedentary behavior levels and patterns, with those living in higher-density locations more sedentary. The findings suggest that country income levels and population density appear to be stronger drivers of the observed differences than sex or rural/urban residential setting. These important findings warrant further examination with larger sample sizes from diverse settings and regions. It is anticipated that the SUNRISE main studies will generate a highly robust sample from which to draw more generalizable conclusions.

Future analyses of country income level differences in sedentary behavior patterns should focus on identifying determinants for such differences. Overall, our findings contribute new insights into global sociodemographic factors associated with young children's sedentary behavior patterns. However, the social and environmental factors that mediate these relationships remain unknown.

The authors thank the SUNRISE participants and their families who made this study possible, and the data collectors at each study site. They thank the SUNRISE Leadership Group and acknowledge the work of the SUNRISE Coordinating Center, Early Start, University of Wollongong. They also acknowledge Prof. Marijka Batterham from the Statistical Consulting Centre at the University of Wollongong for providing statistical advice. Thanks also go to PAL Technologies (Glasgow, Scotland) for their support in the purchasing of activPALs and the analysis of the data. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation and do not constitute endorsement by the American College of Sports Medicine.

All authors contributed to the design and conceptualization of the study. Katharina E Kariippanon, Kar Hau Chong, Xanne Janssen, Simone A. Tomaz, Evelyn H. C. Ribeiro, Nyaradzai Munambah, and Anthony D. Okely contributed to the conceptualization, drafting, review, and approval of the manuscript. Kar Hau Chong conducted the analyses. Cecilia H. S. Chan, P. W. Prasad Chathurangana, Catherine E. Draper, Asmaa El Hamdouchi, Wong Jyh Eiin, Alex A. Florindo, Amy S. Ha, Guan Hongyan, Mohammad Sorowar Hossain, Dong Hoon Kim, Thanh Van Kim, Denise Koh, Marie Löf, Bang Nguyen Pham, Bee Koon Poh, John J. Reilly, Amanda E. Staiano, Adang Suherman, Chiaki Tanaka, Hong Kim Tang, Mark S. Tremblay, E. Kipling Webster, and V. Pujitha Wickramasinghe reviewed and approved the final manuscript.

This study was funded by the American Council on Exercise, USA; Beijing Health System High Level Talents Training Project, China; Biomedical Research Foundation, Dhaka, Bangladesh; Canadian Institutes of Health Research Planning and Dissemination Grant; Conselho Nacional de Pesquisa e Desenvolvimento Científico e Tecnologico–CNPq Research; Department of National Planning and Monitoring, PNG Government; Early Start, University of Wollongong, Australia; Faculty of Health Sciences at the University of the Witwatersrand, Johannesburg, South Africa; Global Challenges Program, University of Wollongong, Australia; Harry Crossley Foundation, South Africa; National Health and Medical Research Council, Australia; NIH–International Research Training Grant; Pham Ngoc Thach University of Medicine, Vietnam; Research University Grant (GUP), Universiti Kebangsaan Malaysia; Sasakawa Sports Research Grant, Sasakawa Sports Foundation, Japan; Stella de Silva Research Grant, Sri Lanka College of Pediatricians, Sri Lanka; The DST-NRF Centre for Excellence in Human Development at the University of Witwatersrand, Johannesburg, South Africa; and The International Society of Behavioral Nutrition and Physical Activity, Pioneers Program.

No author has entered into an agreement with the funder that may have limited their ability to complete the research as planned. All authors have had full control of the primary data from their respective study sites.

The authors have no competing financial or personal interests to declare.

EPIDEMIOLOGY

REFERENCES

1. Dempsey PC, Biddle SJH, Buman MP, et al. New global guidelines on sedentary behaviour and health for adults: broadening the behavioural targets. *Int J Behav Nutr Phys Act*. 2020;17(1):151.
2. Cliff DP, Hesketh KD, Vella SA, et al. Objectively measured sedentary behaviour and health and development in children and adolescents: systematic review and meta-analysis. *Obes Rev*. 2016;17(4):330–44.
3. Poitras VJ, Gray CE, Janssen X, et al. Systematic review of the relationships between sedentary behaviour and health indicators in the early years (0–4 years). *BMC Public Health*. 2017;17(5 Suppl):868.
4. Tremblay MS, LeBlanc AG, Kho ME, et al. Systematic review of sedentary behaviour and health indicators in school-age children and youth. *Int J Behav Nutr Phys Act*. 2011;8:98.
5. Jones RA, Hinkley T, Okely AD, Salmon J. Tracking physical activity and sedentary behavior in childhood: a systematic review. *Am J Prev Med*. 2013;44(6):651–8.
6. Pereira JR, Zhang Z, Sousa-Sá E, Santos R, Cliff DP. Correlates of sedentary time in young children: a systematic review. *Eur J Sport Sci*. 2021;21(1):118–30.
7. Pereira JR, Cliff DP, Sousa-Sá E, Zhang Z, Santos R. Prevalence of objectively measured sedentary behavior in early years: systematic review and meta-analysis. *Scand J Med Sci Sport*. 2019;29(3):308–28.
8. McCrorie P, Mitchell R, Macdonald L, et al. The relationship between living in urban and rural areas of Scotland and children's physical activity and sedentary levels: a country-wide cross-sectional analysis. *BMC Public Health*. 2020;20(1):304.
9. Briceño G, Céspedes J, Leal M, Vargas S. Prevalence of cardiovascular risk factors in schoolchildren from a rural and urban area in Colombia. *Biomedica*. 2018;38(4):545–54.
10. Xu F, Li J, Liang Y, et al. Associations of residential density with adolescents' physical activity in a rapidly urbanizing area of mainland China. *J Urban Health*. 2010;87(1):44–53.
11. Steene-johannessen J, Hansen BH, Dalene KE, et al. Variations in accelerometry measured physical activity and sedentary time across Europe—harmonized analyses of 47,497 children and adolescents. *Int J Behav Nutr Phys Act*. 2020;17(1):38.

12. Dias KI, White J, Jago R, et al. International comparison of the levels and potential correlates of objectively measured sedentary time and physical activity among three-to-four-year-old children. *Int J Environ Res Public Health*. 2019;16(11):1929.
13. UN. World urbanization prospects. *Demogr Res*. 2014;12(January):197–236.
14. World Health Organization [WHO]. Sedentary Lifestyle: A Global Public Health Problem. World Health Day 2002. Published 2002. https://www.who.int/docstore/world-health-day/2002/fact_sheets4.en.pdf
15. Rezende LFM, Sá TH, Mielke GI, Viscondi JYK, Rey-López JP, Garcia LMT. All-cause mortality attributable to sitting time: analysis of 54 countries worldwide. *Am J Prev Med*. 2016;51(2):253–63.
16. Ding D, Lawson KD, Kolbe-Alexander TL, et al. The economic burden of physical inactivity: a global analysis of major non-communicable diseases. *Lancet*. 2016;388(10051):1311–24.
17. Okely AD, Kariippanon KE, Guan H, et al. Global effect of COVID-19 pandemic on physical activity, sedentary behaviour and sleep among 3- to 5-year-old children: a longitudinal study of 14 countries. *BMC Public Health*. 2021;21(1):940.
18. World Health Organization [WHO]. *WHO Guidelines on Physical Activity, Sedentary Behaviour for Children under 5 Years of Age*. 2019. http://www.who.int/iris/handle/10665/311664
19. World Health Organization [WHO]. Web Annex. Evidence profiles. In: *WHO guidelines on physical activity, sedentary behaviour and sleep for children under 5 years of age. World Health Organization*. Published 2019. https://apps.who.int/iris/bitstream/handle/10665/325147/WHO-NMH-PND-2019.4-eng.pdf?sequence=1&isAllowed=y%0Ahttp://www.who.int/iris/handle/10665/311664%0Ahttps://apps.who.int/iris/handle/10665/325147.
20. Okely T, Reilly JJ, Tremblay MS, et al. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-income, middle-income and high-income countries: the SUNRISE study protocol. *BMJ Open*. 2021;11(10):e049267.
21. Janssen X, Cliff DP, Reilly JJ, et al. Validation of activPAL defined sedentary time and breaks in sedentary time in 4- to 6-year-olds. *Pediatr Exerc Sci*. 2014;26(1):110–7.
22. Penpraze V, Reilly JJ, MacLean CM, et al. Monitoring of physical activity in young children: how much is enough? *Pediatr Exerc Sci*. 2006;18(4):483–91.
23. Aadland E, Nilsen AKO, Ylvisåker E, Johannessen K, Anderssen SA. Reproducibility of objectively measured physical activity: reconsideration needed. *J Sports Sci*. 2020;38(10):1132–9.
24. De Craemer M, Decraene M, Willems I, Buysse F, Van Driessche E, Verbestel V. Objective measurement of 24-hour movement behaviors in preschool children using wrist-worn and thigh-worn accelerometers. *Int J Environ Res Public Health*. 2021;18(18):9482.
25. Carlson JA, Tuz-Zahra F, Bellettiere J, et al. Validity of two awake wear-time classification algorithms for activPAL in youth, adults, and older adults. *J Meas Phys Behav*. 2021;4(2):151–62.
26. Okely T, Reilly JJ, Tremblay MS, Kariippanon KE. Cross-sectional examination of 24-hour movement behaviours among 3- and 4-year-old children in urban and rural settings in low-, middle-, and high-income countries: the SUNRISE study protocol. *BMJ Open*. 2021;11(10):e049267.
27. UNESCO. *A Recommendation on the Method to Delineate Cities, Urban and Rural Areas for International Statistical Comparisons*; 2020.
28. Broyles ST, Denstel KD, Church TS, et al. The epidemiological transition and the global childhood obesity epidemic. *Int J Obes Suppl*. 2015;5(S2):S3–8.
29. Ma C, Zhang Y, Zhao M, Bovet P, Xi B. Physical activity and sedentary behavior among young adolescents in 68 LMICs, and their relationships with national economic development. *Int J Environ Res Public Health*. 2020;17(21):7752.
30. Määttä S, Konttinen H, Haukkala A, Erkkola M, Roos E. Preschool children's context-specific sedentary behaviours and parental socioeconomic status in Finland: a cross-sectional study. *BMJ Open*. 2017;7(11):e016690.
31. Chokshi DA, Farley TA. Health. Changing behaviors to prevent noncommunicable diseases. *Science*. 2014;345(6202):1243–4.
32. International Society for Physical Activity and Health (ISPAH). *ISPAH's Eight Investments That Work for Physical Activity*. Vol November; 2020. www.ISPAH.org/Resources
33. Stevenson M, Thompson J, de Sá TH, et al. Land use, transport, and population health: estimating the health benefits of compact cities. *Lancet*. 2016;388(10062):2925–35.
34. Tremblay MS. Introducing 24-hour movement guidelines for the early years: a new paradigm gaining momentum. *J Phys Act Health*. 2020;17(1):92–5.
35. Oyeyemi A, Larouche R. Prevalence and correlates of active transportation in developing countries. In: Larouche R, editor. *Children's Active Transportation*. Canada: University of Lethbridge Lethbridge; 2018. pp. 173–91.
36. Loh R, Stamatakis E, Folkerts D, Allgrove JE, Moir HJ. Effects of interrupting prolonged sitting with physical activity breaks on blood glucose, insulin and triacylglycerol measures: a systematic review and meta-analysis. *Sports Med*. 2020;50(2):295–330.
37. Chandrasekaran B, Pesola AJ, Rao CR, Arumugam A. Does breaking up prolonged sitting improve cognitive functions in sedentary adults? A mapping review and hypothesis formulation on the potential physiological mechanisms. *BMC Musculoskelet Disord*. 2021;22(1):274.