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Human development index, children's health-related quality of life and movement behaviors: a compositional data analysis

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Abstract

Purpose Health-related quality of life has been related to physical activity, sedentary behavior, and sleep among children from developed nations. These relationships have rarely been assessed in developing nations, nor have behaviors been considered in their true context, as mutually exclusive and exhaustive parts of the movement behavior composition. This study aimed to explore whether children's health-related quality of life is related to their movement behavior composition and if the relationship differs according to human development index.

Methods Children aged 9–11 years ($n=5855$), from the 12-nation cross-sectional observational International Study of Childhood Obesity, Lifestyle and the Environment 2011–2013, self-reported their health-related quality of life (KIDSCREEN-10). Daily movement behaviors were from 24-h, 7-day accelerometry. Isometric log-ratio mixed-effect linear models were used to calculate estimates for difference in health-related quality of life for the reallocation of time between daily movement behaviors.

Results Children from countries of higher human development index reported stronger positive relationships between health-related quality of life and moderate-to-vigorous physical activity, relative to the remaining behaviors ($r=0.75$, $p=0.005$) than those from lower human development index countries. In the very high human development index strata alone, health-related quality of life was significantly related to the movement behavior composition ($p=0.005$), with moderate-to-vigorous physical activity (relative to remaining behaviors) being positively associated with health-related quality of life.

Conclusions The relationship between children's health-related quality of life and their movement behaviors is moderated by their country's human development index. This should be considered when 24-h movement behavior guidelines are developed for children around the world.

Keywords Physical activity · Sedentary behavior · Sleep · Compositional data · Human development index

Introduction

Children's health-related quality of life (HRQoL) encompasses their perceptions of the impact of their physical, mental, social, and emotional health status [1]. It is being increasingly utilized as a general health indicator in population-based epidemiological studies [2, 3]. In particular, research has aimed to identify correlates of HRQoL, with the intention of informing targeted interventions and public health policies.

To date, studies of lifestyle and HRQoL have predominantly been conducted in developed nations (e.g., Australia [4, 5], Canada [6], France [7]). Our recent cluster analysis among children from 12 nations was the first to examine the relationship between HRQoL and lifestyle behavior clusters among children from nations of low and medium human development index (HDI) [8]. We found that among most nations, HRQoL was highest among children with modest moderate-to-vigorous physical activity (MVPA) and sedentary time in combination with low screen time and a healthy diet. However, cluster analysis simply identifies groups of

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children with common lifestyle behaviors, and subsequent post hoc analyses are used to explore the relationship between cluster membership and HRQoL [9]. If a specific behavior is unimportant in defining cluster membership (as in Dumuid et al. [8], where sleep duration was consistent between the clusters), it is not possible to examine to influence of that behavior. However, it is possible that behaviors unimportant to cluster definition are in fact important correlates of HRQoL.

Previous studies have investigated the relationship between HRQoL and individual movement behaviors [4–6, 10, 11]; however, these studies have neglected to analyze the data within their 24-h context, as parts of the human movement composition [i.e., daily time spent in sleep, sedentary time, light physical activity (LPA) and MVPA]. One of these behaviors cannot change without compensatory changes in the remaining behaviors; therefore, the behaviors are co-dependent and should not be considered in isolation from each other. As previous studies have not included all behaviors, the relationship between children's HRQoL and their daily movement behaviors remains unclear [12, 13]. It is also unknown whether any relationship would be consistent among children of different nations. It is of particular interest whether a nation's HDI influences this relationship as recent studies have suggested that developing nations are undergoing an epidemiological transition, specifically, as developing nations become increasingly westernized, children accumulate less MVPA and more sedentary behavior [14–16].

This study's aim was to use compositional data analysis to investigate the relationship between children's self-reported HRQoL and 24-h movement data and to explore whether this relationship was consistent across nations of differing HDI.

Patients and methods

Study design and participants

Data from the cross-sectional International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) were used. A detailed description of the ISCOLE protocol can be found in Katzmaryzk et al. [17].

Children aged 9–11 years were recruited from schools in study sites from Australia, Brazil, Canada, China, Colombia, England, Finland, India, Kenya, Portugal, South Africa, and the United States. Each site contributed approximately 500 children, with a total sample of 7372. Data collection was carried out between September 2011 and December 2013. Participants were excluded if they were missing data for HRQoL ($n=94$), and/or valid accelerometry ($n=1165$) and/or sociodemographic covariates [child sex and body mass index (BMI) z-score, number of parents and number of siblings residing in the home and highest parental education level] ($n=258$). The final analytical sample was $n=5855$ (79% of all data analyzable).

Ethics

The ISCOLE coordinators obtained ethical approval from the Institutional Review Board of the Pennington Biomedical Research Center in Baton Rouge, Louisiana, USA. Each site also gained site-specific ethical approval. Written informed parental consent and child assent were obtained from all individual participants included in the study.

Measurement

Health-related quality of life

The KIDSCREEN-10 [18] was completed by child participants. The KIDSCREEN-10 is the brief form of a European measure (KIDSCREEN-54) [1], however; it has been used and validated in many non-European nations [19] (e.g., Mexico [20], Chile [21], Iran [22], Kenya and Uganda [23]). The KIDSCREEN-10 consists of 10 questions about children's physical activity, energy and fitness, moods and emotions, social and leisure participation, social and family relationships, cognitive capacity, and school experience. Responses are recorded on a 5-point scale, and reversed when appropriate to ensure that higher scores indicate better HRQoL. Each participant's scores were summed, transformed to Rasch person-parameters, from which T values with a mean of 50 and a standard deviation of approximately 10 [18] were calculated.

Daily 24-h movement behaviors: the composition

Daily time spent in sleep, sedentary time, LPA, and MVPA was determined from 24-h, 7-day hip-worn accelerometry (Actigraph GT3X+ [ActiGraph LLC, Pensacola, FL, USA]). The overall average daily wear time was 22.8 h. Valid participants had ≥ 10 h/day waking wear time (at least 4 days, including at least one weekend day) and ≥ 160 min total sleep time for at least three nights (including one weekend night) [24]. Accelerometry data were sampled at 80 Hz, downloaded in 1-s epochs, and subsequently aggregated into 60-s epochs for the application of a published algorithm to estimate nocturnal sleep duration [25]. Waking-wear time was re-processed in 15-s epochs and subjected to Evenson's cut-points to determine duration of sedentary time, LPA, and MVPA [26]. The weighted averages (weekdays:weekend days at 5:2) of each behavior (sleep, sedentary time, LPA, and MVPA) were used as parts of the daily movement composition. Each participant's daily composition was normalized to sum to 1440 min.

Sociodemographic covariates

Parents completed a questionnaire [17] regarding their child's sex, family composition (number of siblings and number of parents), and highest level of education achieved by either parent (1 = less high school or some high school; 2 = completed high school and some post-secondary; 3 = bachelor degree and post-graduate). Participants' body mass index (BMI) was calculated [BMI = weight (kg)/height (m^2)] from measured weight (TANITA Corporation, Tokyo, Japan [27]) and height (Seca 213 portable stadiometer, Hamburg, Germany), and then expressed as *z*-scores using age- and sex-specific World Health Organization reference data [28].

Data analysis

Data analysis consisted of (1) comparing the relationship between HRQoL and the daily movement behavior composition between study sites, (2) exploring the relationship between HRQoL and the movement composition, and changes to the movement composition, among children from nations of varying HDI.

Analyses were conducted in R [29] using the compositions [30], robCompositions [31], and lme4 [32] packages. Analyses performed at the site-level used mixed-effects multivariable linear regression, with HRQoL as the dependent variable. Daily movement behaviors (time spent in sleep, sedentary time, LPA, and MVPA) were considered as the explanatory variables. However, these four behaviors are mutually exclusive and exhaustive parts of the daily movement behavior composition: altogether they must always sum to 24 h each day. This means that time in one behavior cannot be changed without a compensatory equal but opposite change among the remaining behaviors. Consequently, these movement behaviors are relative data, and one should not be considered in isolation from the remaining behaviors. However, due to multi-collinearity, it is not usually possible to include all the behaviors in one model. This can be overcome by using compositional data analysis [33]. Compositional data analysis for daily movement behavior data is described in detail by Chastin et al. [33], and has been compared to traditional non-compositional methods of analysis elsewhere [13, 34]. Briefly, compositional data analysis involves expressing the daily movement behaviors in relative terms, as a set of isometric log-ratio coordinates [35]. The log ratios cannot be created if there are zero values in any movement behavior, as the logarithm of zero is undefined. Procedures for dealing with zero values are presented elsewhere [36]. The behavior data were checked for zeros; none were present. In this analysis, a specific isometric log-ratio transformation was used so that the first coordinate had MVPA as its numerator and the geometric mean of the remaining behaviors (sleep, sedentary time, and LPA) as its denominator. The first coordinate therefore contained all information regarding MVPA, relative to the remaining behaviors. This enabled interpretation of the first regression coefficient from the model (beta1) as the HRQoL association of MVPA relative to the remaining behaviors [13, 33, 37]. Covariates (parental education, number of siblings, number of parents, BMIz, and sex) were included in the models as fixed effects, and school was added as a random effect (random intercepts). Subsequently, Pearson's product moment correlation coefficient was calculated between HDI at all the sites and the strength of the relationship between HRQoL and MVPA [relative to the remaining behaviors—as quantified by the first regression coefficients (beta 1) obtained from each site's mixed-effects multivariable linear regression model]. The analysis was repeated for sleep, sedentary time, and LPA. The models were checked for linearity, normality, homoscedasticity, and outliers to ensure assumptions were not violated.

To explore the second aim, participants were stratified according to their country's HDI into very high HDI (Australia, the United States, Canada, Finland, England, and Portugal), high HDI (Brazil and Colombia) and medium–low HDI (China, South Africa, India, and Kenya). Mixed-effects multivariable linear regression (random intercepts) was used as for Aim 1; however, the multi-level nested nature of the sampling design (participants recruited from schools nested within countries) was accounted for in the models. The relationship between HRQoL and daily movement behaviors was explored using the models to estimate HRQoL for a range of different daily movement compositions. Daily movement behaviors were iteratively changed from the baseline daily composition (the compositional mean) to represent incremental 15-min increase/decrease in one behavior (e.g., MVPA) while all remaining behaviors were relatively decreased/increased to maintain a total daily maximum of 24 h (procedural detail and example R code can be found in Supplementary File 1). This process was repeated for each behavior. Subsequently, the difference in estimated HRQoL between the baseline (predicted mean) composition and the new compositions was calculated and plotted to aid interpretation. Effect-sizes (ES) for difference between estimates (conditional on country and school) were calculated as a ratio of the model residual standard deviation.

Results

Included participants were more likely to be female ($p < 0.001$), have parents of higher education ($p < 0.001$), and have fewer siblings ($p < 0.001$) than excluded participants. Included participants also had lower BMI *z*-scores ($p < 0.001$). However, effect-sizes of differences between included and excluded participants were small (Cramer's $V = 0.00$–0.28 for nominal variables, and Cohen's $d = 0.05$–0.12 for continuous variables) (Supplementary File 2, Tables e1–e3). Participant characteristics are summarized in Tables 1 and 2.

Across most study sites (8 out of 12), HRQoL was positively associated with both sleep and MVPA (both relative to the remaining behaviors) (Table 3). Conversely, HRQoL was negatively associated with sedentary time (relative to remaining behaviors) at eight sites, and LPA (relative to remaining) at seven sites. Children from nations of higher HDI status reported higher associations between HRQoL and MVPA (relative to remaining behaviors) than children from low HDI nations ($r = 0.75$, $p = 0.005$) (Fig. 1). No relationships were observed between HDI and the HRQoL associations of sleep, sedentary time or LPA (Supplementary File 3, Fig. e1).

In stratified analyses, the movement composition was significantly positively associated with children's HRQoL in the very high HDI strata ($p = 0.005$) (Fig. 2) (see Supplementary Table e6 for regression parameters). In particular, MVPA (relative to remaining behaviors) was positively associated with HRQoL ($p < 0.001$). In the high HDI and low–medium HDI groups, children's movement composition was not significantly associated with HRQoL ($p = 0.51$ and $p = 0.84$, respectively) (Supplementary File 4, Tables e4–e6); however, the association between MVPA and HRQoL tended to be negative (Figs. 3, 4), with larger associations in the low–medium HDI strata.

Among children of very HDI nations, regression models estimated HRQoL to increase by 0.8 units (ES = 0.08) when MVPA was increased by 30 min from the daily mean (while remaining behaviors were simultaneously decreased to maintain the daily total of 1440 min) and to decrease by 1.3 units (ES = 0.14) with a 30-min decrease of MVPA (and corresponding increase of remaining behaviors) (Fig. 2) (Supplementary File 5, Table e7). In contrast, children from high and low–medium HDI nations had an estimated decrease of 0.1 (ES = 0.01) and 0.3 units (ES = 0.03) of HRQoL respectively, with a 30-min relative increase in MVPA, and an estimated increase of 0.1 (ES = 0.01; high HDI) and 0.5 (ES = 0.05; low–medium HDI) with a 30-min relative decrease in MVPA (Figs. 3, 4) (Supplementary File 5, Table e8, e9).

Discussion

This study investigated the relationship between children's self-reported HRQoL and their 24-h movement behaviors, and whether the HDI level of children's residential country moderated this relationship.

Table 1 Participant sociodemographic characteristics by study site

	Total	Sex, *n* (%)	Highest parental education level, *n* (%)			Number of parents, *n* (%)		Number of siblings, *n* (%)					zBMI
	n	Boys	1	2	3	≤1	≥2	0	1	2	3	≥4	Mean (SD)
Australia	435	203 (47)	47 (49)	201 (46)	185 (43)	71 (16)	364 (84)	31 (7)	199 (46)	119 (27)	55 (13)	31 (7)	0.57 (1.12)
England	376	161 (43)	43 (11)	190 (51)	175 (47)	81 (22)	295 (78)	36 (10)	175 (47)	96 (26)	40 (11)	29 (8)	0.41 (1.08)
Canada	500	203 (41)	41 (10)	132 (26)	358 (72)	67 (13)	433 (87)	62 (12)	250 (50)	118 (24)	44 (9)	26 (5)	0.41 (1.21)
Finland	433	195 (45)	45 (12)	235 (54)	186 (43)	82 (19)	351 (81)	60 (14)	173 (40)	118 (27)	49 (11)	33 (8)	0.27 (1.04)
Portugal	577	241 (42)	42 (262)	193 (33)	122 (21)	69 (12)	508 (88)	159 (28)	310 (54)	80 (14)	18 (3)	10 (2)	0.82 (1.15)
USA	446	183 (41)	41 (26)	191 (43)	229 (51)	145 (33)	301 (67)	45 (10)	140 (31)	118 (26)	81 (18)	62 (14)	0.72 (1.28)
Brazil	435	211 (49)	49 (103)	234 (54)	98 (23)	80 (18)	355 (82)	87 (20)	183 (42)	107 (25)	34 (8)	24 (6)	0.87 (1.41)
Colombia	821	403 (49)	49 (247)	424 (52)	150 (18)	173 (21)	648 (79)	70 (9)	262 (32)	237 (29)	111 (14)	141 (17)	0.20 (1.04)
China	462	238 (52)	52 (161)	207 (45)	94 (20)	23 (5)	439 (95)	305 (66)	136 (29)	14 (3)	4 (1)	3 (1)	0.73 (1.54)
India	526	237 (45)	45 (28)	114 (22)	384 (73)	28 (5)	498 (95)	119 (23)	344 (65)	51 (10)	7 (1)	5 (1)	0.21 (1.37)
South Africa	387	152 (39)	39 (185)	146 (38)	56 (14)	146 (38)	241 (62)	21 (5)	144 (37)	118 (30)	49 (13)	55 (14)	0.31 (1.28)
Kenya	457	208 (46)	46 (64)	212 (46)	181 (40)	116 (25)	341 (75)	47 (10)	128 (28)	148 (32)	61 (13)	73 (16)	−0.02 (1.22)

zBMI Body mass index *z*-score (World Health Organization), *USA* United States

Parent education levels are *1* <high school and some high school, *2* completed high school and some post-secondary (e.g., vocational diploma or certificate); *3* bachelor degree and post-graduate

Table 2 Participant outcome characteristics by study site

	HRQoL T score (SD)	Sleep (min/day)	Sedentary (min/day)	LPA (min/day)	MVPA (min/day)
Australia	49.81 (8.50)	577	486	314	63
England	50.05 (8.74)	579	508	291	62
Canada	51.23 (9.25)	555	521	308	56
Finland	52.66 (8.67)	523	547	301	69
Portugal	52.97 (10.16)	508	571	308	53
USA	50.77 (10.30)	542	531	320	48
Brazil	47.31 (7.80)	526	514	345	55
Colombia	49.92 (8.16)	531	508	337	65
China	51.16 (11.51)	531	573	293	43
India	48.16 (9.21)	523	526	345	45
South Africa	49.66 (11.23)	561	495	324	60
Kenya	47.13 (9.96)	525	508	339	67

Time use data are presented as compositional means: no standard deviations are presented for compositional means because univariate variability is irrelevant for compositional data

HRQoL health-related quality of life, *LPA* light physical activity, *MVPA* moderate-to-vigorous physical activity

Table 3 The relationship between HRQoL and movement behavior isometric log-ratio regression coefficients among the 12 ISCOLE sites

	HDI	$\hat{\beta}_1$ *ilr* sleep	$\hat{\beta}_1$ *ilr* SED	$\hat{\beta}_1$ *ilr* LPA	$\hat{\beta}_1$ *ilr* MVPA
Australia ($n=435$)	0.929	0.54	−0.83	−2.89	3.18
United States ($n=446$)	0.910	−3.69	3.17	−4.71	5.24
Canada ($n=500$)	0.908	−6.90	0.24	4.28	2.38
Finland ($n=433$)	0.882	2.31	−3.72	0.64	0.77
England ($n=376$)	0.863	4.70	−1.09	−4.83	1.22
Portugal ($n=577$)	0.809	1.59	−2.36	−0.06	0.83
Brazil ($n=435$)	0.718	6.08	0.06	−5.25	−0.89
Colombia ($n=821$)	0.710	0.16	−2.38	1.70	0.53
China ($n=462$)	0.687	4.23	−2.62	−1.71	0.10
South Africa ($n=387$)	0.619	1.95	−2.40	1.24	−0.79
India ($n=526$)	0.547	−2.12	4.66	−2.28	−0.26
Kenya ($n=457$)	0.509	−1.16	−3.31	5.19	−0.72

HRQoL Health-related quality of life, *ISCOLE* International Study of Childhood Obesity, Lifestyle and the Environment, *HDI* human development index, obtained from the United Nations Development Programme; Human Development Report 2011. Sustainability and equity: a better future for all. New York NY: Palgrave Macmillan; 2011, $\hat{\beta}_1$ *ilr* first isometric log-ratio regression coefficient from the linear models, representing one behavior relative to all remaining behaviors, *SED* sedentary time, *LPA* light physical activity, *MVPA* moderate-to-vigorous physical activity

A positive relationship between HRQoL and time spent in MVPA (relative to remaining behaviors) was found among children from very high HDI nations; however, effect-sizes for 30-min displacements of MVPA were small. Previous studies in developed nations have similarly reported positive relationships between children's HRQoL and MVPA [5, 6, 10, 38, 39]. Children accumulating more MVPA may report higher HRQoL because of the direct physical (e.g., reduced fatigue, improved fitness, control of body weight) and psychological (e.g., mental stimulation, emotional well-being) benefits [40, 41]. Furthermore, there may be indirect benefits of time spent in MVPA [41] (e.g., socialization, increased self-esteem with improved physical competency, and/or biologic mechanisms such as elevated endorphin levels).

Findings suggest that the association between HRQoL and time spent in MVPA is not linear or symmetrical. For example, 30 minutes less MVPA (relative to the remaining behaviors) were associated with an estimated difference in HRQoL of −1.3, compared with an estimated increase of +0.8 with 30 minutes more MVPA. Carson et al. [42] found a similar asymmetry between time spent in MVPA and cardiometabolic health markers in their

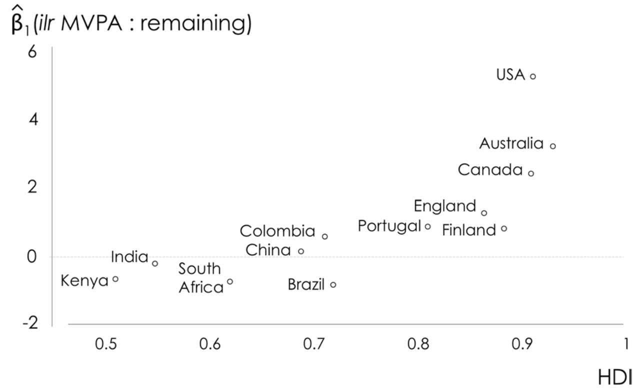

Fig. 1 The relationship between HDI and isometric log-ratio regression coefficients of MVPA relative to the remaining behaviors. *HDI* human development index, obtained from the United Nations Development Programme; Human Development Report 2011. Sustainability and equity: a better future for all. New York NY: Palgrave Macmillan; 2011. $\hat{\beta}_1$ *ilr MVPA* first isometric log-ratio regression coefficient from the linear models, representing moderate-to-vigorous physical activity relative to all remaining behaviors

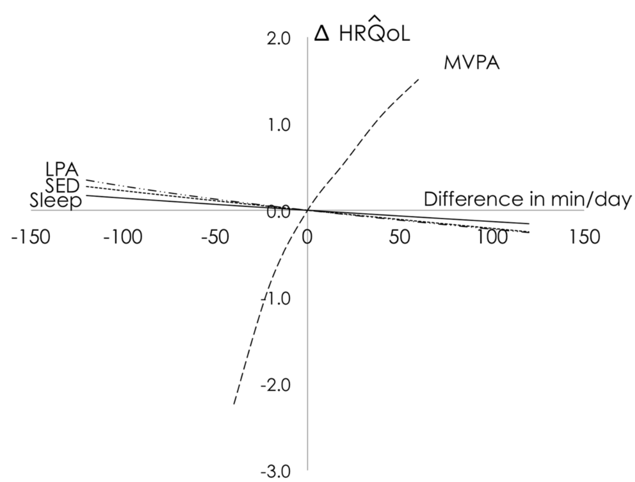

Fig. 2 Estimated difference in HRQoL: very high human development index (Australia, the United States, Canada, Finland, England, and Portugal). *HRQoL* health-related quality of life *T*-score. *MVPA* Moderate-to-vigorous physical activity. *LPA* Light physical activity. *SED* Sedentary time. Difference in movement behaviors (min/day) is calculated from the compositional mean, and is relative to all the remaining behaviors

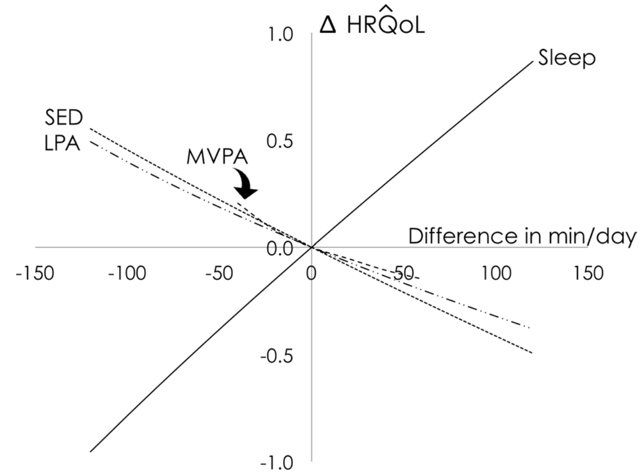

Fig. 3 Estimated difference in HRQoL: high human development index (Brazil and Colombia). *HRQoL* health-related quality of life *T*-score, *SED* sedentary time. *LPA* light physical activity, *MVPA* moderate-to-vigorous physical activity. Difference in movement behaviors (min/day) is calculated from the compositional mean, and is relative to all the remaining behaviors

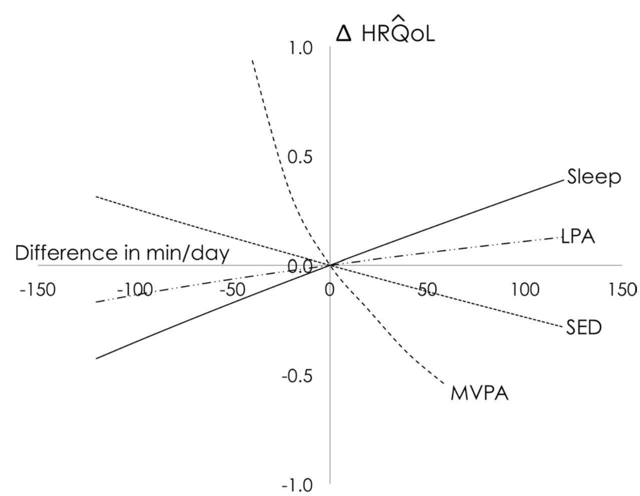

Fig. 4 Estimated difference in HRQoL: low to medium human development index (China, South Africa, India, and Kenya). *HRQoL* health-related quality of life *T*-score. *LPA* Light physical activity, *SED* sedentary time, *MVPA* moderate-to-vigorous physical activity. Difference in movement behaviors (min/day) is calculated from the compositional mean, and is relative to all the remaining behaviors

compositional data analysis of 5217 Canadian children (6–17 years). Collectively, these findings imply that the maintenance of time spent in MVPA is of particular importance to children's health and well-being, and highlight the need for interventions focused around events and occasions when time spent in MVPA typically tends to decline, e.g., during school summer holidays [43], months of extreme weather conditions [44], and the transition to adolescence [45].

Interestingly, the relationship between HRQoL and time spent in MVPA (relative to remaining behaviors) was not significant among children from nations of high and low–medium HDI. In fact, HRQoL tended to be negatively associated with relative time spent in MVPA (but not statistically significantly so). These relationships have rarely been investigated in countries of low–medium or even high HDI. We are aware of only one such study, among Malaysian children (aged 9–11 years, $n=156$) [46]. Self-reported

HRQoL was positively associated with accelerometer-measured time in MVPA, but the association was mitigated when the analysis was adjusted for zBMI. While the authors recommended involvement in MVPA to promote HRQoL, any benefit may be mediated by lower zBMI, rather than by additional time spent in MVPA per se. The relationship between children's HRQoL and zBMI itself varies among different cultural contexts; while the majority of studies in developed countries have reported an inverse relationship, some studies in developing countries have found a positive relationship [47], or none at all [48]. It is therefore important for HRQoL research to adjust for the influence of zBMI, as we have done in the present study.

Our findings suggest that the relationship between children's HRQoL and MVPA may be context-specific, and not solely underpinned by physical or psychological mechanisms. The method by which MVPA is accumulated may be important [49, 50]. In highly developed countries, children tend to accrue a considerable portion of their MVPA through participation in sport [51] and discretionary activities such as active play, which may entail an entourage of process benefits such as social interaction, parental support and skill mastery. It is possible that in countries of lower development, children's MVPA may be predominantly accumulated as a result of necessity, e.g., work, household chores or active transport. We further explored these possibilities using child self-report data regarding physical activity participation (Supplementary File 6, Table e10) from the ISCOLE Diet and Lifestyle Questionnaire [17]. We found that, indeed, children from different HDI strata participated in different types of physical activity. More children from countries of very high HDI participated in extra-curricular sport than children from low–medium HDI countries (59% vs. 41%; sport teams and 33% vs. 25%; dance/martial arts). More children from very high HDI countries reported walking as their mode of transport to school than children from low–medium HDI countries (35% vs. 29%), however, of the subsample of children that walked to school, children from very high HDI countries reported markedly less time spent walking to school than children from low and medium HDI countries (2.8% of very high HDI spent > 30 min/day, compared with 12% from low to medium HDI).

The present study found no clear relationships between children's HRQoL and their time spent in sleep, sedentary time or LPA. Yet, it is notable that, in low–medium HDI countries only, sleep duration (although non-significant) tended to have a positive relationship with HRQoL. This is possibly because sleep may have been, by necessity, displaced by MVPA (e.g., work, chores, and active transport), or sedentary behaviors (e.g., study in a competitive academic environment). Sleep duration may be not positively associated with HRQoL among children from very high HDI countries because they are already achieving optimum sleep duration, where further increases have little benefit. In this study, children in very high HDI countries had longer sleep duration (544 min/day) than children from lower HDI countries (high HDI: 529 min/day; low–medium HDI: 534 min/day).

This study's strengths include the use of compositional data analysis methods to enable the inclusion of all daily movement behaviors [12]. Furthermore, data were collected from a large, international sample using standardized procedures. However, the findings of this study must be considered in the context of certain limitations. First, data were cross-sectional, precluding any assessment of directionality of relationships. Second, children were recruited from sites in urban and suburban centres and may not be representative of the nation's population [52]. Third, measures of daily movement data were obtained through accelerometry, which does not always distinguish between sitting and standing postures or behavioral context (e.g., play vs. sport vs. active transport vs. labor). Furthermore, full 24-h data were not captured for every participant. Nonetheless, compositional data analysis with isometric log ratios assumes that relative and not absolute quanta of time are related to health outcomes. Accordingly, proportions of time spent in each component are considered, rather than absolute measures of time (min/day). In the descriptive analyses presented in this study, these proportions were linearly adjusted to sum to 1440, so that the values could be interpreted in min/day. However, this assumed that the relative time spent in behaviors during non-wear was the same as during wear time. Finally, HRQoL was collected via the KIDSCREEN-10, which, although validated in many non-European developing countries [19], was originally developed for European children.

Conclusion

The determinants of HRQoL are multi-faceted and complex. An understanding of the context of movement behaviors, i.e., a qualitative description of how and why behaviors are accumulated, is crucial for future HRQoL research and for the economic evaluation of HRQoL gains [e.g., quality-adjusted life years (QALY)]. Furthermore, the mechanism by which daily behaviors may influence HRQoL should be investigated through experimental research. Direct effects (e.g., biological changes leading to reduced future cardiovascular risk) may have a more sustained benefit to QALY than indirect, or process effects (e.g., improved self-esteem), which may provide transient benefit whilst a positive behavior change is in process [41]. Future studies must respect the compositional nature of movement behavior data and account for the peculiarities of their unique sample space.

In summary, children's HRQoL is associated with their movement behavior composition; however, the direction, strength, and statistical significance of associations are moderated by their country's HDI. The link between children's HRQoL and movement behaviors appears to differ according to the context in which they are accumulated. This has important implications for how children's 24-h behavior guidelines encompassing sleep, sedentary behavior, and physical activity are constructed and adopted by different countries around the world.

Data availability The data that support the findings of this study are available from Peter T. Katzmarzyk (Peter.Katzmarzyk@pbrc.edu) but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Pennington Biomedical Research Center.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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