



HAL
open science

Cross-sectional and prospective associations between children's 24-h time use and their health-related quality of life: a compositional isotemporal substitution approach

Sarah Yi Xuan Tan, Natarajan Padmapriya, Jonathan Bernard, Jia Ying Toh, Hwee-Lin Wee, Kok Hian Tan, Fabian Kok Peng Yap, Yung Seng Lee, Yap-Seng Chong, Keith Godfrey, et al.

► To cite this version:

Sarah Yi Xuan Tan, Natarajan Padmapriya, Jonathan Bernard, Jia Ying Toh, Hwee-Lin Wee, et al.. Cross-sectional and prospective associations between children's 24-h time use and their health-related quality of life: a compositional isotemporal substitution approach. *The Lancet Regional Health - Western Pacific*, 2023, 41, pp.100918. 10.1016/j.lanwpc.2023.100918 . hal-04632254

HAL Id: hal-04632254

<https://hal.science/hal-04632254>

Submitted on 2 Jul 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **Cross-sectional and prospective associations between children's 24-hour time use and**
2 **their health-related quality of life: a compositional data analysis and isotemporal**
3 **substitution approach**

4 Sarah Yi Xuan Tan¹, Natarajan Padmapriya^{1,2}, Jonathan Y Bernard^{3,4}, Jia Ying Toh³, Hwee-
5 Lin Wee^{1,5}, Kok Hian Tan^{6,7}, Fabian Kok Peng Yap^{6,7,8}, Yung Seng Lee^{3,9,10}, Yap-Seng
6 Chong^{2,3}, Keith M Godfrey^{11,12}, Johan G Eriksson^{2,3,13}, Lynette Pei-Chi Shek^{3,9,10}, Chuen
7 Seng Tan¹, Mary Foong-Fong Chong^{1,3*}, Falk Müller-Riemenschneider^{1,14*}

8 * Co-senior authors

9 ¹ Saw Swee Hock School of Public Health, National University of Singapore, Singapore,
10 Singapore

11 ² Department of Obstetrics and Gynaecology, Yong Loo Lin School of Medicine, National
12 University of Singapore, Singapore, Singapore

13 ³ Singapore Institute for Clinical Sciences (SICS), Agency for Science, Technology and
14 Research (A*STAR), Singapore, Singapore

15 ⁴ Université Paris Cité and Université Sorbonne Paris Nord, Centre for Research in
16 Epidemiology and Statistics (CRESS), Inserm, Inrae, F-75004, Paris, France

17 ⁵ Department of Pharmacy, Faculty of Science, National University of Singapore, Singapore,
18 Singapore

19 ⁶ Department of Paediatrics, KK Women's and Children's Hospital, Singapore, Singapore

20 ⁷ Duke-National University of Singapore Medical School, Singapore, Singapore

21 ⁸ Lee Kong Chian School of Medicine, Nanyang Technological University, Singapore,
22 Singapore

23 ⁹ Khoo Teck Puat-National University Children's Medical Institute, National University
24 Health System, Singapore, Singapore

25 ¹⁰ Department of Paediatrics, Yong Loo Lin School of Medicine, National University of
26 Singapore, Singapore, Singapore

27 ¹¹ Medical Research Council Lifecourse Epidemiology Centre, University of Southampton,
28 Southampton, United Kingdom

29 ¹² NIHR Southampton Biomedical Research Centre, University of Southampton and
30 University Hospital Southampton NHS Foundation Trust, Southampton, United Kingdom

31 ¹³ Department of General Practice and Primary Health Care, University of Helsinki and
32 Folkhälsan Research Center, Helsinki, Finland

33 ¹⁴ Digital Health Centre, Berlin Institute of Health, Charité – Universitätsmedizin Berlin,
34 Berlin, Germany

35

36 **Abstract**

37 **Background:** Promoting children's movement behaviours may be an important approach to
38 optimising their health-related quality of life (HRQoL). However, the relationships between
39 children's movement behaviours and HRQoL remain unclear.

40 **Methods:** We examined the cross-sectional and prospective associations between movement
41 behaviours objectively assessed using accelerometers at ages 8 and 10 years and self-reported
42 HRQoL scores (physical and emotional well-being, self-esteem, relationship with family and
43 friends, and school functioning) at age 10 years among 370 children in a local birth cohort
44 using compositional data analysis and isotemporal substitution techniques.

45 **Findings:** Cross-sectionally, light and moderate-to-vigorous intensity physical activities were
46 positively associated with children's self-esteem ($\beta=15.88$, [2.64, 29.12]) and relationship
47 with friends ($\beta=10.23$, [3.76, 16.71]) scores respectively. Prospectively, sleep showed a
48 positive trend with overall HRQoL ($\beta=10.95$, [-0.91, 22.81]) and school functioning
49 ($\beta=17.33$, [-0.66, 35.33]) scores, while inactivity was associated with lower overall HRQoL
50 ($\beta=-10.12$, [-19.26, -0.98]), relationship with friends ($\beta=-16.74$, [-31.93, -1.55]) and school
51 functioning ($\beta=-15.38$, [-29.24, -1.52]) scores. Children's movement behaviours were not
52 associated with their physical and emotional well-being, or relationship with family scores.

53 The isotemporal substitution analyses suggest that increasing time spent in physical activity
54 and/or sleep at the expense of inactivity would benefit children's HRQoL.

55 **Interpretation:** Generally, sleep and physical activity were positively associated with
56 HRQoL, while inactivity was negatively associated with HRQoL. Our findings highlight the
57 complexity of the relationship between children's movement behaviours and HRQoL and
58 form the basis for future research.

59 **Funding:** Singapore National Research Foundation, Singapore Institute for Clinical Sciences,
60 Agency for Science Technology and Research.

61

62 **Introduction**

63 Research on health-related quality of life (HRQoL), a subjective multi-dimensional construct
64 encompassing physical, psychological, and social health,^[1,2] has been gaining traction.^[3]
65 Being a strong predictor of morbidity and mortality,^[4,5] suboptimal HRQoL presents an
66 important public health concern, especially since awareness of the importance of optimal
67 functioning beyond the absence of ill health is increasing.^[6] Concerningly, HRQoL of
68 children in various countries was observed to decline with age;^[7-9] in Singapore, this decline
69 was observed to occur from the age of 10 years.^[8]

70 While this decline may be attributed to lesser leisure time, increased academic pressure, and
71 the transition into puberty as children grow older,^[7] poorer HRQoL among older children
72 may also be associated with their changes in sleep, inactivity, and physical activity (of light
73 and moderate-to-vigorous intensity) patterns, collectively referred to as movement
74 behaviours.^[10] Studies have found that children who were more active had better physical and
75 psychosocial functioning as they had healthier weight status, better self-esteem, opportunities
76 for socialisation, and increased endorphin levels that promotes a sense of pleasure and well-
77 being^[11-13]. Sleep on the other hand was associated with mood and emotional regulation^[14,15]
78 wherein inadequate sleep was associated with poorer HRQoL among children aged 9 to 11
79 years.^[16] Though the mechanisms of inactivity on HRQoL were less explored,^[10] it is
80 postulated that time spent in inactivity may displace physical activity and/or sleep, explaining
81 the negative associations with HRQoL.^[10]

82 As children grow older and gain autonomy over their lifestyle aspects, they become less
83 physically active and increasingly sedentary.^[17-22] A recent study in the Growing Up in
84 Singapore Towards healthy Outcomes (GUSTO) cohort revealed that between the ages of 5.5
85 and 8 years, children's movement behaviours transitioned towards being more sedentary and
86 less physically active.^[23] Other studies have found that particularly from the age of around 10
87 years, children tend to be more sedentary and have less physical activity and inadequate sleep
88 as they transition into adolescence.^[16,24]

89 Promoting children's movement behaviours may therefore be an approach to improve their
90 self-perceived well-being and functioning, leading to functional, optimal lives. Yet, the
91 relationship between children's movement behaviours and their HRQoL remains unclear. To
92 date, most studies have only examined single behaviours in association with HRQoL, without
93 accounting for the interrelatedness of the movement behaviours in a constrained 24-hour
94 day,^[10] resulting in inaccurate estimates of association.^[25,26] Further, existing studies have
95 largely been cross-sectional by design and are thus susceptible to reverse causation,
96 warranting prospective or longitudinal studies to confirm these trends.^[10,11,27] HRQoL
97 research in children have also been concentrated in Western contexts, with limited
98 representation of Asian populations.^[11,27] Since perception of HRQoL reflects one's life
99 experiences^[28] which could depend on political, social, economic, and environmental
100 contexts,^[29] findings from other populations have limited generalisability to other contexts.

101 The limitations of the existing literature warrants further investigations to bridge important
102 knowledge gaps relating to children's movement behaviours and their HRQoL, particularly in
103 the Asian context. The present study aimed to fill these gaps by examining the cross-sectional
104 and prospective associations between children's movement behaviours at 10 and 8 years and
105 their HRQoL at 10 years. To appropriately account for the compositional nature of 24-hour
106 time-use and the interrelatedness of the movement behaviours, a compositional data analysis
107 approach was implemented. We further predicted the change in HRQoL score at 10 years
108 when 30 minutes is reallocated between the four movement behaviours at 10 and 8 years.
109 These findings seek to contribute to the current evidence base regarding the movement
110 behaviours of children in an Asian sample and their HRQoL.

112 **Methods**

113 *Study design*

114 Child participants in the present study were part of the GUSTO mother-offspring cohort.
115 Details of the cohort have been published previously.^[30] In brief, the GUSTO study was
116 started in 2009. Pregnant women were recruited from two major public maternity units in
117 Singapore, KK Women's and Children's Hospital, and National University Hospital. To be
118 eligible, they had to be aged at least 18 years, of Chinese, Malay, or Indian ethnicity with a
119 same-ethnicity partner, Singapore citizens or permanent residents, and were intending to
120 deliver in one of the two above-mentioned maternity units and remain in Singapore for the
121 following five years. All participants provided written informed consent at enrolment. The
122 study was ethically reviewed and approved by the National Healthcare Group Domain
123 Specific Review Board and the SingHealth Centralised Institutional Review Board.

124 *Data collection*

125 *Covariates*

126 Sociodemographic information was collected from medical records at birth, or via
127 interviewer administered questionnaires administered at various stages of follow up. These
128 included variables such as the child's sex, ethnicity, and maternal education at age 5 years,
129 used as proxy for socioeconomic status. Child body mass index (BMI) was derived based on
130 anthropometric measurements obtained at the follow up visit at age 8 years. Height and
131 weight were measured up to thrice using a weighing scale (SECA model 803) and
132 stadiometer (SECA model 213, Hamburg, Germany), respectively; repeated measures were
133 averaged. BMI was calculated using the formula: weight (in kg) / squared height (in m²) and
134 classified as underweight, normal weight, and overweight based on age- and sex-specific cut-
135 offs for Singaporean children ^[31]. For participants with missing covariate information (n=39
136 for maternal education at age 5 years, n=2 for BMI at age 8 years), data from the preceding
137 timepoint (pregnancy week 11 and age 7 years respectively) were used to impute missing
138 information.

139 *24-h movement behaviours*

140 During the follow up at ages 8 and 10 years, participants were asked to wear a triaxial
141 accelerometer (ActiGraph wGT3X+-BT; ActiGraph Pensacola, FL, USA) on their non-
142 dominant wrist using a non-removable strap to monitor their movement behaviours at both
143 timepoints. Accelerometers were initialized with a sampling rate of 80 Hz, and were attached

144 to the child's non-dominant wrist with a non-removable strap during the clinic visits at both
145 timepoints. Parents were instructed to remove the device from the child's wrist on the ninth
146 day following the visit, allowing for 7 complete days of continuous, 24-hour data capture.
147 Upon return of the device, raw data were extracted with the ActiLife software, then processed
148 using the GGIR package available in R (version 2.0-0) according to a published protocol.^[32]
149 In brief, raw accelerometer signals were auto-calibrated and expressed as gravity-corrected
150 vector magnitude units (Euclidean Norm Minus One [ENMO]). Non-wear time was
151 estimated based on standard deviations and value range of each accelerometer axis at 60-
152 minute windows in 15-minute increments. To be considered valid and included for analyses,
153 each participant's accelerometer data must have a minimum of 16 hours of valid wear time
154 per day for at least three days (two weekdays and one weekend day). Of the valid days, non-
155 wear time in blocks of 15 minutes were imputed based on the mean value from other valid
156 days.^[33] Time spent in sleep, inactivity (ENMO<35.0 mg), light intensity physical activity
157 (LPA) (ENMO 35.0–200 mg), and moderate-to-vigorous intensity physical activity (MVPA)
158 (ENMO>200 mg) were derived based on previously established protocols and acceleration
159 thresholds according to van Hees, Hildebrand, and colleagues.^[34-36] For the present study,
160 inactivity was used as proxy for sedentary behaviour (defined as activities “ ≤ 1.5 metabolic
161 equivalents while in a sitting, reclining or lying posture”^[37]) since wrist-worn accelerometers
162 cannot determine whole body posture. Sleep was quantified as the sum of night sleep and
163 naps, defined as periods exceeding 15 minutes of sustained inactivity during wear time.
164 Weekday and weekend day data were weighted using the ratio of 5:2 and averaged, such that
165 the averaged data were representative of a full seven-day week.

166 *Health-related quality of life*

167 HRQoL was collected using the KINDL-Kid questionnaire administered to the child
168 participants during their follow up at age 10 years. This questionnaire has been validated
169 among local Singaporean children.^[38] It comprises 24 questions that assess six domains of
170 HRQoL (four questions per domain, each question with five answer categories), namely
171 physical well-being, emotional well-being, self-esteem, relationship with family, relationship
172 with friends, and school functioning, which are summed to provide an overall HRQoL score.
173 Domain-specific (original scale: 4 to 20) and overall HRQoL scores (original scale: 24 to
174 120) were transformed to a scale of 0 to 100 to facilitate interpretation.

175

176 *Statistical analyses*

177 Participants with complete data were included in the analyses. Test for differences in
178 characteristics between included and excluded participants were conducted using Pearson's
179 Chi-squared tests. Mean and standard deviation values described the distribution of
180 movement behaviour durations and HRQoL scores among included participants.

181 Compositional data analysis was performed to explain the relationship between movement
182 behaviour compositions and HRQoL^[26] based on previously developed methods by Dumuid
183 and colleagues for epidemiological research.^[39] Time spent in each movement behaviour at
184 age 10 years was expressed as isometric log ratios (ilr) and transformed using sequential
185 binary partitioning,^[40] such that the first coordinate presented one movement behaviour (e.g.,
186 sleep) as the numerator, and the geometric mean of the remaining behaviours (i.e., inactivity,
187 LPA, and MVPA) as the denominator.^[25] This coordinate therefore contains information
188 regarding one movement behaviour as a variable relative to the other three behaviours.^[39] A
189 total of four sets of ilr coordinates were purposefully created to ensure that each behaviour
190 could be represented as a numerator relative to the remaining behaviours as the first
191 coordinate.^[39] As each set of ilr coordinates were included as predictors in a model, four
192 models were generated for each of the four sets. The beta coefficients and 95% confidence
193 interval from the regression models of the first coordinates of each set of ilr coordinates were
194 interpreted as the positive or negative association between each movement behaviour, relative
195 to the remaining behaviours, on each HRQoL outcome. The models were adjusted for the
196 following potential confounders: sex, ethnicity, maternal education level, and the child's
197 weight status at age 8 years. Given that the year in which children turned 10 years old
198 coincided with the COVID-19 pandemic which may influence their HRQoL, we also
199 accounted for whether the child was followed up at age 10 years before or after the onset of
200 the COVID-19 pandemic.

201 Using the models created in the compositional data analysis, isotemporal substitution was
202 performed to investigate the theoretical effects of replacing specific amounts of time in one
203 behaviour with that of another, while time spent in other behaviours remained constant.^[41]
204 For example, to increase time spent in sleep by 30 minutes, we decreased the time spent in
205 MVPA by 30 minutes, with the time spent in inactivity and LPA remaining the same.

206 To examine the prospective associations between the movement behaviours and HRQoL, the
207 above analyses were repeated using movement behaviours at age 8 years as the exposure
208 variable and HRQoL at 10 years as the outcome variable. Similarly, the models were adjusted
209 for the following covariates: sex, ethnicity, maternal education level, child's weight status at
210 age 8 years, and whether the participant was followed up before or after the onset of the
211 COVID-19 pandemic at age 10 years.

212 All analyses were performed in RStudio (version 1.4.1717) using the compositions,^[42]
213 robCompositions,^[43] lmtest,^[44] and car^[45] packages.

214

215 *Role of the funding source*

216 The funders had no role in study design, data collection, data analysis, data interpretation, or
217 writing of the report. The corresponding author had full access to all the data in the study and
218 had final responsibility for the decision to submit for publication.

219

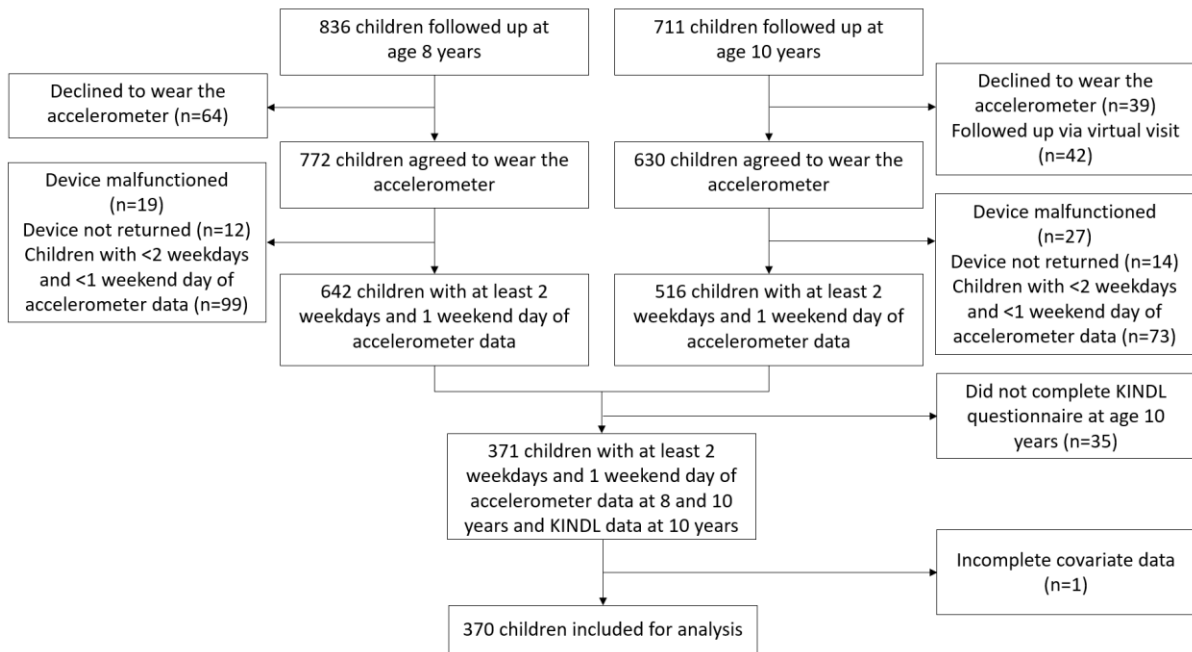
220 **Results**

221 *Participant characteristics*

222 Of the 836 and 711 children followed up at ages 8 and 10 years, respectively, 370 children
223 with valid accelerometer data at both time points and complete KINDL questionnaire and
224 covariate data were included in the present analyses (Figure 1). Most were girls (50.5%), of
225 Chinese ethnicity (58.4%), of mothers with at least a degree-level education (49.2%), of
226 normal weight (78.9%), and completed their KINDL questionnaire after the onset of the
227 COVID-19 pandemic in Singapore (94.9%) (Table 1). Included and excluded participants did
228 not differ in characteristics significantly (Supplementary Table 1).

229 Children's time spent in sleep, inactivity, LPA and MVPA at ages 8 and 10 years, and their
230 HRQoL scores at age 10 years were presented in Table 1.

231



232

233

Figure 1. Flowchart of the GUSTO participants examined in the present study

234

235

	Study sample (n=370)
Sex, n (%)	
Boys	183 (49.5)
Girls	187 (50.5)
Ethnicity, n (%)	
Chinese	216 (58.4)
Malay	101 (27.3)
Indian	53 (14.3)
Maternal education, n (%)	
No education/Primary/Secondary	112 (30.3)
Post-secondary	76 (20.5)
Degree and above	182 (49.2)
Weight status at age 8 years, n (%)	
Underweight	43 (11.6)
Normal weight	292 (78.9)
Overweight	35 (9.5)
Completion of KINDL questionnaire, n (%)	
After onset of COVID-19 pandemic	351 (94.9)
Before onset of COVID-19 pandemic	19 (5.1)

Movement behaviours at age 8 years, mean (s.d.)

Sleep, h/day	8.8 (0.7)
Inactivity, h/day	8.4 (1.1)
LPA, h/day	5.6 (0.9)
MVPA, min/day	71.5 (28.6)

Movement behaviours at age 10 years, mean (s.d.)

Sleep, h/day	8.5 (0.8)
Inactivity, h/day	9.6 (1.2)
LPA, h/day	5.0 (1.0)
MVPA, min/day	49.6 (23.9)

HRQoL scores at age 10 years, mean (s.d.)

Total HRQoL	66.4 (12.8)
Physical well-being	79.3 (14.7)
Emotional well-being	74.1 (16.3)
Self-esteem	46.0 (23.0)
Relationship with family	71.3 (17.6)
Relationship with friends	65.8 (21.5)
School functioning	62.0 (19.7)

237 Abbreviations: light intensity physical activity (LPA), moderate-to-vigorous intensity
238 physical activity (MVPA), health-related quality of life (HRQoL)

240 *Cross-sectional associations between movement behaviours and HRQoL*

241 Table 2 presents the association between each movement behaviour (e.g. sleep) relative to the
242 remaining behaviours (i.e. inactivity, LPA, and MVPA).

243 Cross-sectionally, LPA was positively associated with self-esteem ($\beta=15.88$ [2.64, 29.12])
244 and MVPA was positively associated with children's relationship with friends ($\beta=10.23$
245 [3.76, 16.71]). We found no cross-sectional association between movement behaviours and
246 overall HRQoL, or with the domains of HRQoL relating to physical and emotional well-
247 being, relationship with family, and school functioning at 10 years of age.

248 Isotemporal substitution analyses largely concurred with the previous findings on positive
249 associations between LPA and MVPA and self-esteem and relationship with friends
250 respectively (Table 3). The analyses suggested that displacement of 30 minutes between sleep
251 and LPA was associated with children's self-esteem: increasing time spent in sleep at the
252 expense of LPA was negatively associated with self-esteem ($\beta=-2.27$ [-4.08, -0.46]), and the
253 inverse was observed when time spent in LPA was increased at the expense of sleep ($\beta=2.18$
254 [0.43, 3.93]). There was also a trend where increasing time spent in inactivity at the expense
255 of LPA was negatively associated with self-esteem ($\beta=-1.39$ [-2.85, 0.07]). Displacement of
256 30 minutes between LPA and MVPA did not influence children's self-esteem.

257 For MVPA, increasing time spent in sleep ($\beta=-9.86$ [-16.26, -3.47]), inactivity ($\beta=-10.02$ [-
258 16.03, -4.01]), or LPA ($\beta=-9.70$ [-16.41, -3.00]) by 30 minutes at the expense of MVPA was
259 negatively associated with their relationship with friends. These associations were of greater
260 magnitude than the inverse, that is when MVPA was increased by 30 minutes at the expense
261 of sleep ($\beta=4.69$ [1.49, 7.88]), inactivity ($\beta=4.85$ [2.09, 7.61]), or LPA ($\beta=4.51$ [0.96, 8.07]),
262 suggesting that the relationship between MVPA and relationship with friends is not
263 symmetrical.

264 Additionally, we observed that increasing time spent in MVPA at the expense of inactivity
265 was positively associated with physical well-being ($\beta=2.02$ [0.08, 3.96]), with the inverse
266 observed when time is reallocated from inactivity to MVPA ($\beta=-4.15$ [-8.37, 0.08]).

267 There were no association between any of the movement behaviours and overall HRQoL,
268 emotional well-being, relationship with family, and school functioning; displacing time
269 between the movement behaviours did not influence these outcome variables (Table 3).

Table 2. Compositional time use at age 8 and 10 years and its association with HRQoL

		Overall HRQoL	Physical well- being	Emotional well-being	Self-esteem	Relationship with family	Relationship with friends	School functioning
Sleep	10 years	-6.72 (-17.29, 3.85)	0.60 (-11.67, 12.88)	-9.63 (-23.10, 3.83)	-16.54 (-35.58, 2.49)	-9.49 (-24.08, 5.10)	-3.19 (-20.64, 14.26)	-2.06 (-18.20, 14.07)
	8 years	10.95 (-0.91, 22.81)	8.94 (-4.78, 22.67)	4.61 (-10.50, 19.72)	8.98 (-12.44, 30.40)	10.72 (-5.56, 26.99)	15.10 (-4.62, 34.83)	17.33 (-0.66, 35.33)
Inactivity	10 years	-1.62 (-9.97, 6.73)	-3.45 (-13.14, 6.25)	1.30 (-9.34, 11.93)	1.68 (-13.36, 16.71)	4.26 (-7.26, 15.78)	-7.12 (-20.91, 6.66)	-6.38 (-19.13, 6.36)
	8 years	-10.12 (-19.26, -0.98)*	-8.91 (-19.48, 1.66)	-6.12 (-17.75, 5.53)	-6.43 (-22.93, 10.06)	-7.13 (-19.67, 5.40)	-16.74 (-31.93, -1.55)*	-15.38 (-29.24, -1.52)*
LPA	10 years	5.40 (-1.95, 12.75)	-1.37 (-9.91, 7.16)	5.22 (-4.15, 14.59)	15.88 (2.64, 29.12)*	5.13 (-5.02, 15.27)	0.08 (-12.05, 12.22)	7.44 (-3.78, 18.67)
	8 years	-0.47 (-8.95, 8.00)	-1.26 (-11.07, 8.55)	0.23 (-10.57, 11.02)	-0.33 (-15.64, 14.97)	-0.63 (-12.27, 10.99)	-1.84 (-15.94, 12.25)	1.00 (-11.85, 13.86)
MVPA	10 years	2.94 (-0.98, 6.86)	4.21 (-0.33, 8.77)	3.12 (-1.88, 8.12)	-1.02 (-8.08, 6.04)	0.10 (-5.30, 5.51)	10.23 (3.76, 16.71)*	1.00 (-4.98, 6.99)
	8 years	-0.35 (-4.78, 4.07)	1.22 (-3.89, 6.34)	1.27 (-4.36, 6.90)	-2.21 (-10.20, 5.77)	-2.95 (-9.01, 3.12)	3.48 (-3.87, 10.84)	-2.95 (-9.66, 3.75)

Analysis performed using multivariable linear regression models with movement behaviours at 8 and 10 years added into separate models; results presented as β (95% confidence intervals). Models were adjusted for sex, ethnicity, maternal education level, child's categorical weight status at age 8 years, and whether the participant was followed up before or after the onset of the COVID-19 pandemic.

An asterisk ('*') denotes statistical significance ($p < 0.05$).

Abbreviations: light intensity physical activity (LPA), moderate-to-vigorous intensity physical activity (MVPA), health-related quality of life (HRQoL)

Table 3. Reallocation of 30 minutes between pairs of movement behaviours at age 10 years and on the predicted change in HRQoL scores at age 10 years (95% confidence intervals)

	Overall HRQoL	Physical well-being	Emotional well-being	Self-esteem	Relationship with family	Relationship with friends	School functioning
Increase sleep							
Reduce inactivity	-0.25 (-1.11, 0.60)	0.19 (-0.80, 1.18)	-0.53 (-1.62, 0.56)	-0.88 (-2.42, 0.65)	-0.66 (-1.84, 0.52)	0.17 (-1.24, 1.58)	0.19 (-1.11, 1.50)
Reduce LPA	-0.82 (-1.83, 0.18)	0.16 (-1.01, 1.32)	-0.95 (-2.23, 0.33)	-2.27 (-4.08, -0.46)*	-0.94 (-2.32, 0.45)	-0.16 (-1.82, 1.49)	-0.79 (-2.32, 0.75)
Reduce MVPA	-3.12 (-6.99, 0.75)	-3.97 (-8.46, 0.53)	-3.43 (-8.36, 1.50)	0.16 (-6.81, 7.13)	-0.56 (-5.90, 4.78)	-9.86 (-16.26, -3.47)*	-1.05 (-6.96, 4.86)
Increase inactivity							
Reduce sleep	0.28 (-0.59, 1.14)	-0.18 (-1.19, 0.82)	0.55 (-0.55, 1.66)	0.93 (-0.63, 2.49)	0.68 (-0.52, 1.87)	-0.15 (-1.58, 1.28)	-0.17 (-1.49, 1.15)

Reduce LPA	-0.57 (-1.38, 0.24)	-0.02 (-0.96, 0.92)	-0.42 (-1.46, 0.61)	-1.39 (-2.85, 0.07)	-0.29 (-1.40, 0.83)	-0.32 (-1.66, 1.02)	-0.96 (-2.20, 0.27)
Reduce MVPA	-2.86 (-6.50, 0.78)	-4.15 (-8.37, 0.08)	-2.90 (-7.54, 1.73)	1.04 (-5.51, 7.59)	0.09 (-4.93, 5.11)	-10.02 (-16.03, -4.01)*	-1.23 (-6.78, 4.33)

Increase LPA

Reduce sleep	0.80 (-0.18, 1.77)	-0.15 (-1.27, 0.98)	0.93 (-0.31, 2.17)	2.18 (0.43, 3.93)*	0.92 (-0.42, 2.26)	0.17 (-1.43, 1.78)	0.73 (-0.76, 2.21)
Reduce inactivity	0.52 (-0.24, 1.29)	0.04 (-0.84, 0.93)	0.37 (-0.60, 1.35)	1.24 (-0.13, 2.62)	0.23 (-0.82, 1.28)	0.33 (-0.93, 1.59)	0.91 (-0.25, 2.08)
Reduce MVPA	-2.34 (-6.40, 1.72)	-4.11 (-8.83, 0.60)	-2.53 (-7.70, 2.65)	2.29 (-5.03, 9.60)	0.33 (-5.28, 5.94)	-9.70 (-16.41, -3.00)*	-0.33 (-6.53, 5.87)

Increase MVPA

Reduce sleep	1.65 (-0.29, 3.58)	1.83 (-0.41, 4.08)	1.88 (-0.59, 4.34)	0.41 (-3.08, 3.89)	0.54 (-2.13, 3.20)	4.69 (1.49, 7.88)*	0.55 (-2.40, 3.50)
Reduce inactivity	1.37 (-0.30, 3.05)	2.02 (0.08, 3.96)*	1.32 (-0.81, 3.45)	-0.53 (-3.54, 2.48)	-0.15 (-2.46, 2.16)	4.85 (2.09, 7.61)*	0.74 (-1.82, 3.29)
Reduce LPA	0.80 (-1.35, 2.75)	1.99 (-0.51, 4.49)	0.90 (-1.85, 3.65)	-1.91 (-5.79, 1.97)	-0.43 (-3.40, 2.54)	4.51 (0.96, 8.06)	-0.24 (-3.53, 3.05)

2.96) 4.49) 3.64) 1.97) 2.55) 8.07)* 3.05)

Results are interpreted as the difference in HRQoL when time spent in one behaviour is increased at the expense of another, while the remaining two behaviours remain constant.

Analysis performed using multivariable linear regression models, results presented as β (95% confidence intervals). Models were adjusted for sex, ethnicity, maternal education level, child's categorical weight status at age 8 years, and whether the participant was followed up before or after the onset of the COVID-19 pandemic.

An asterisk ('*') denotes statistical significance ($p < 0.05$).

Abbreviations: light intensity physical activity (LPA), moderate-to-vigorous intensity physical activity (MVPA), health-related quality of life (HRQoL)

266 *Prospective associations between movement behaviours and HRQoL*

267 Prospectively, inactivity was negatively associated with overall HRQoL ($\beta=-10.12$ [-19.26, -
268 0.98]), relationship with friends ($\beta=-16.74$ [-31.93, -1.55]), and school functioning ($\beta=-15.38$
269 [-29.24, -1.52]), while sleep showed a positive trend with overall HRQoL ($\beta=10.95$ [-0.91, -
270 22.81]) and school functioning ($\beta=17.33$ [-0.66, 35.33]). There were no associations between
271 the movement behaviours and the domains of HRQoL relating to physical and emotional
272 well-being, self-esteem, and relationship with family, though the direction of associations
273 suggested that sleep and inactivity were consistently positively and negatively associated
274 with overall HRQoL and all HRQoL domains, respectively. LPA and MVPA were not
275 associated with overall HRQoL and any of the HRQoL domains (Table 2).

276 Isotemporal substitution analyses suggested that increasing sleep at the expense of inactivity
277 may be positively associated with overall HRQoL ($\beta=1.05$ [0.06, 2.05]), relationship with
278 friends ($\beta=1.60$ [-0.05, 3.25]), and school functioning ($\beta=1.64$ [0.13, 3.14]). The inverse was
279 observed for overall HRQoL ($\beta=-1.05$ [-2.05, -0.06]), relationship with friends ($\beta=-1.59$ [-
280 3.25, 0.07]), and school functioning ($\beta=-1.64$ [-3.15, -0.12]) when inactivity was increased at
281 the expense of sleep (Table 4).

282 Displacing time between the movement behaviours did not influence physical well-being,
283 emotional well-being, self-esteem, and relationship with family (Table 4).

Table 4. Reallocation of 30 minutes between pairs of movement behaviours at age 8 years and the predicted change in HRQoL scores at age 10 years (95% confidence intervals)

	Overall HRQoL	Physical well-being	Emotional well-being	Self-esteem	Relationship with family	Relationship with friends	School functioning
Increase sleep							
Reduce inactivity	1.05 (0.06, 2.05)*	0.90 (-0.25, 2.04)	0.54 (-0.72, 1.81)	0.77 (-1.02, 2.56)	0.89 (-0.47, 2.25)	1.60 (-0.05, 3.25)	1.64 (0.13, 3.14)*
Reduce LPA	0.56 (-0.50, 1.62)	0.53 (-0.70, 1.76)	0.20 (-1.15, 1.56)	0.45 (-1.47, 2.38)	0.56 (-0.90, 2.02)	0.87 (-0.90, 2.64)	0.74 (-0.87, 2.36)
Reduce MVPA	0.71 (-1.77, 3.18)	-0.21 (-3.07, 2.65)	-0.44 (-3.59, 2.71)	1.57 (-2.89, 6.04)	2.04 (-1.35, 5.43)	-1.09 (-5.19, 3.02)	2.36 (-1.39, 6.11)
Increase inactivity							
Reduce sleep	-1.05 (-2.05, -0.06)*	-0.89 (-2.05, 0.26)	-0.54 (-1.81, 0.73)	-0.77 (-2.57, 1.03)	-0.89 (-2.26, 0.47)	-1.59 (-3.25, 0.07)	-1.64 (-3.15, -0.12)*
Reduce LPA	-0.46 (-1.33, 0.40)	-0.34 (-1.34, 0.66)	-0.32 (-1.42, 0.78)	-0.29 (-1.86, 1.27)	-0.30 (-1.49, 0.89)	-0.68 (-2.12, 0.76)	-0.85 (-2.16, 0.47)
Reduce MVPA	-0.32 (-2.53, 1.89)	-1.08 (-3.63, 1.47)	-0.96 (-3.78, 1.86)	0.83 (-3.16, 5.50)	1.17 (-1.86, 4.36)	-2.64 (-6.31, 1.03)	0.77 (-2.58, 4.04)

	1.89)	1.48)	1.85)	4.81)	4.20)	1.04)	4.12)
Increase LPA							
Reduce sleep	-0.59 (-1.63, 0.45)	-0.54 (-1.75, 0.66)	-0.22 (-1.54, 1.11)	-0.48 (-2.36, 1.40)	-0.59 (-2.01, 0.84)	-0.90 (-2.63, 0.83)	-0.80 (-2.38, 0.78)
Reduce inactivity	0.50 (-0.34, 1.33)	0.38 (-0.59, 1.34)	0.34 (-0.72, 1.40)	0.31 (-1.19, 1.82)	0.33 (-0.82, 1.47)	0.75 (-0.64, 2.13)	0.89 (-0.38, 2.15)
Reduce MVPA	0.15 (-2.53, 2.83)	-0.73 (-3.83, 2.37)	-0.64 (-4.05, 2.77)	1.12 (-3.71, 5.95)	1.48 (-2.19, 5.15)	-1.94 (-6.39, 2.51)	1.61 (-2.46, 5.67)
Increase MVPA							
Reduce sleep	-0.67 (-2.32, 0.99)	-0.06 (-1.97, 1.86)	0.18 (-1.93, 2.29)	-1.16 (-4.15, 1.82)	-1.49 (-3.76, 0.78)	0.36 (-2.39, 3.11)	-1.83 (-4.34, 0.69)
Reduce inactivity	0.42 (-0.95, 1.79)	0.86 (-0.72, 2.45)	0.73 (-1.01, 2.48)	-0.37 (-2.85, 2.10)	-0.57 (-2.45, 1.31)	2.00 (-0.27, 4.28)	-0.14 (-2.22, 1.94)
Reduce LPA	-0.08 (-1.96, 1.80)	0.50 (-1.68, 2.67)	0.39 (-2.00, 2.79)	-0.69 (-4.08, 2.71)	-0.90 (-3.48, 1.68)	1.27 (-1.86, 4.40)	-1.03 (-3.89, 1.82)

Results are interpreted as the difference in HRQoL when time spent in one behaviour is increased at the expense of another, while the remaining two behaviours remain constant.

Analysis performed using multivariate linear regression models, results presented as β (95% confidence intervals). Models were adjusted for sex, ethnicity, maternal education level, child's categorical weight status at age 8 years, and whether the participant was followed up before or after the onset of the COVID-19 pandemic.

An asterisk ('*') denotes statistical significance ($p < 0.05$).

Abbreviations: light intensity physical activity (LPA), moderate-to-vigorous intensity physical activity (MVPA), health-related quality of life (HRQoL)

284 **Discussion**

285 Our study is, to our knowledge, the first to examine the cross-sectional and prospective
286 associations between the full movement spectrum of children and their overall and domain-
287 specific HRQoL. We utilised objectively assessed movement behaviour data and self-
288 reported HRQoL data from a sample of Asian children to better understand the complex
289 relationships between children's movement behaviours and HRQoL. We found that specific
290 behaviours were associated with specific aspects of HRQoL, wherein some relationships
291 emerged cross-sectionally and others prospectively. Generally, our findings suggest that
292 greater sleep and physical activity were associated with better HRQoL (overall and/or
293 domain-specific scores), while spending more time in inactivity was associated with worse
294 HRQoL. Isotemporal substitution analyses supported these findings, where HRQoL scores
295 increased when sleep and/or physical activity displaced inactivity.

296 In the present study, we found positive cross-sectional associations between LPA and self-
297 esteem, and between MVPA and the relationship with friends HRQoL domain. To further
298 contextualise these findings, our isotemporal substitution analyses revealed that increasing
299 LPA only at the expense of sleep was positively associated with self-esteem, with the inverse
300 observed when sleep displaced LPA; LPA displacing or being displaced by inactivity or
301 MVPA did not influence self-esteem scores. On the other hand, increasing MVPA, regardless
302 at the expense of sleep, inactivity, or LPA, was positively associated with childrens'
303 relationship with friends; an inverse, exponential, and non-symmetrical relationship was
304 observed when MVPA was displaced. The asymmetrical trend observed for MVPA is in line
305 with previous studies among children of a similar age group,^[11,46] which may be attributed to
306 already suboptimal MVPA durations in children,^[47,48] whereby further reducing time in
307 MVPA could exacerbate the outcomes (e.g., relationship with friends in the present sample)
308 associated with low MVPA. Our findings support current evidence, with associations
309 between physical activity and various measures of self-esteem and psychosocial well-being
310 widely reported. The positive association between physical activity and self-esteem (and its
311 constructs such as self-worth and self-concept)^[49-51] may be explained by physical activity
312 contributing to the mastery of one's physique and perception of their physical appearance
313 (i.e. body image).^[12] Physical activity also provides opportunities for socialisation,^[12]
314 promotes social skills,^[52] reduces feelings of social isolation,^[53] and increases perceived
315 social acceptance,^[54] all of which are associated with better psychosocial outcomes including
316 social relationships.^[55] However, we note that associations in the present study were only

317 observed for either physical activity intensity (i.e., either LPA or MVPA and not both). We
318 postulate that there were differing contexts for the light and moderate-to-vigorous intensity
319 physical activities among children in the present study (e.g., active transport, active play,
320 organised sport), contributing to the difference in HRQoL domains associated with these
321 behaviours. Contextual information regarding physical activity was not examined in the
322 present study and should be explored in future research. Further, we only observed these
323 associations cross-sectionally and not prospectively, limiting causal inference. This suggests
324 that the relationships may be bidirectional, wherein children with higher self-esteem and
325 better relationship with their friends may instead be more inclined to partake in physical
326 activity.^[56]

327 To our knowledge, there has not been a prospective or longitudinal study that investigated all
328 four movement behaviours in relation to HRQoL whilst properly accounting for the
329 interrelatedness of the movement behaviours. We bridge this gap by analysing prospectively
330 and found that sleep was positively associated with overall HRQoL and school functioning,
331 while inactivity was negatively associated with overall HRQoL, relationship with friends, and
332 school functioning. The isotemporal substitution analyses revealed that increasing sleep at the
333 expense of inactivity may benefit overall HRQoL, relationship with friends, and school
334 functioning, with an inversed relationship of similar magnitude observed when inactivity
335 displaced sleep. Current published evidence suggests that sleep may be associated with
336 overall HRQoL, mood and emotional regulation, which could be postulated to influence
337 social relationships and academic performance.^[14,15,57-59] These would explain our
338 observations that when sleep is displaced, there was a negative impact on these HRQoL
339 domains and consequentially, overall HRQoL scores. However, existing studies, including
340 the present, have only assessed total sleep duration without considering other sleep
341 dimensions, such as sleep disturbances, patterns and quality, that could drive associations
342 between sleep and HRQoL,^[11,27,60] warranting future studies to examine the role of these
343 dimensions in children's HRQoL more deeply.^[61]

344 Interestingly, we identified that HRQoL is impacted significantly only when inactivity (and
345 not LPA or MVPA) displaces sleep. Though we did not examine the context of the activities
346 children engaged in, we postulate that these associations were driven by screen-viewing,
347 which are typically sedentary in nature.^[62] Studies have found screen-viewing to be
348 negatively associated with overall HRQoL, including HRQoL domains relating to children's

349 physical, psychosocial, mental, emotional, and/or school functioning,^[10] cross-sectionally^[63]
350 and prospectively.^[56,64-66] Further, night-time screen-viewing has been negatively associated
351 with sleep and HRQoL among children.^[67] Hence, the negative associations observed
352 between inactivity and HRQoL in the present study may be attributed to screen-viewing
353 during periods of inactivity. It is worth noting that these associations were only observed
354 prospectively and not cross-sectionally. As we did not collect HRQoL information from
355 children at the “baseline” of the present study (i.e. age 8 years), our ability to control for
356 baseline HRQoL when assessing prospective relationships was limited. Findings therefore
357 warrant cautious interpretation.

358 Other than the aforementioned findings, we did not observe any other association between the
359 movement behaviours and HRQoL (overall and/or domain-specific scores). Notably, physical
360 activity (i.e. LPA and MVPA) was not associated with overall HRQoL, and none of the four
361 movement behaviours were associated with physical well-being, emotional well-being, and
362 relationship with family, both cross-sectionally and prospectively. Engagement in physical
363 activity has been thought to improve physical well-being, improve mood, and reduce
364 symptoms associated with depression and anxiety.^[12,68] However, findings on associations
365 between physical activity and HRQoL have been equivocal, with some studies demonstrating
366 a positive association and others none.^[10,13,69] Even among studies that have found an
367 association between physical activity and HRQoL, the beta coefficients often do not reach a
368 minimally important difference.^[13] Hence, more research is warranted to confirm associations
369 and/or establish causal relationships between physical activity and HRQoL in children.

370 Regarding sleep, though previous studies have found positive associations between sleep and
371 HRQoL,^[70,71] these studies are sparse, with limited discussion on specific HRQoL domains
372 such as physical or emotional well-being, or on the mechanisms underlying the
373 associations.^[59] Previous studies have also suggested that sleep may be associated with
374 children’s relationship with their family. Poor family relationships (e.g. marital conflicts,
375 family conflicts) were found to negatively influence children’s sleep, in particular, their sleep
376 quality,^[72] while secure parent-child relationships were associated with better sleep.^[73] We
377 did not observe significant associations between sleep and these HRQoL domains in the
378 present study, which may be attributed to suboptimal sleep durations of children in our
379 sample. In an earlier study of children in the same cohort, only a small proportion of children
380 aged 8 years met the recommended sleep duration (9 – 11 hours).^[23] We postulate that

381 children in our study sample (at both age 8 and 10 years) may not have achieved sufficient
382 sleep to manifest positive impacts on these aspects of their HRQoL. Further, we did not
383 consider other dimensions of sleep beyond duration in the present analyses, warranting future
384 studies to bridge these knowledge gaps to enhance understanding of associations between
385 sleep and HRQoL in children.

386 In relation to inactivity, previous studies have largely found negative associations between
387 inactivity (or sedentary behaviour) and HRQoL in children, including physical and emotional
388 well-being,^[10,74] which we did not confirm. However, it is worth noting that these studies
389 typically assessed screen-viewing behaviours as proxy for inactivity, which cannot be
390 assessed objectively, and may not necessarily corroborate with total inactivity time. In the
391 present analysis, we did not review screen-viewing as a component of children's 24-hour
392 time use as the four behaviours examined were mutually exclusive parts of a 24-hour day^[25]
393 and screen-viewing would overlap with one or possibly more than one behaviour (e.g.
394 inactivity and/or LPA such as using screen-based devices while walking), complicating the
395 compositional data analysis technique implemented. Future research examining children's
396 movement behaviours and HRQoL should explore accounting for screen-viewing duration
397 and the context of screen-viewing behaviours in their analyses.

398 We also wish to highlight that differences in our findings compared to other studies may also
399 be attributed to other factors that could have had bigger, more direct impacts on the HRQoL
400 of children in our sample compared to their movement behaviours. In an earlier study among
401 children aged 10 to 15 years in Singapore, ethnicity was found to be associated with
402 children's HRQoL, with Malay children reporting lower HRQoL than their Chinese and
403 Indian counterparts.^[8] Previous studies examining the relationship between HRQoL and
404 movement behaviours of children were largely conducted in homogenous samples.^[11,27] In
405 multi-cultural populations like Singapore, ethnic differences could play an important role in
406 children's HRQoL, attenuating the role of movement behaviours in this relationship. Other
407 factors including sex and SES may also influence children's movement behaviours and/or
408 perceptions of their well-being.^[8] Future studies investigating other factors influencing the
409 associations between children's movement behaviours and their HRQoL, particularly in non-
410 homogenous samples are therefore warranted.

411 The present study has several strengths. We assessed children's movement behaviours using
412 accelerometers, reducing the risk of bias by allowing high quality data across the full

413 continuum of movement behaviours to be objectively collected. To the best of our
414 knowledge, our study is the first to date to have examined the prospective associations
415 between all four movement behaviours and HRQoL and HRQoL domains, allowing us to
416 ascertain temporality of the observed relationships. Further, we implemented compositional
417 data analysis techniques to fully account for the interrelatedness of the movement behaviours
418 in our analyses.^[11,39] These strengthened our conclusions regarding children's movement
419 behaviours and their HRQoL – our findings were largely in line with literature in that
420 physical activity and sleep were positively associated with HRQoL, while inactivity was
421 negatively associated with HRQoL. However, we also revealed that the relationships between
422 children's movement behaviours and HRQoL were complex and that conclusions, at least in
423 the present sample, could not be easily made. Notwithstanding, our findings contribute to
424 current understanding of the relationships between children's movement behaviours and their
425 HRQoL, especially in the less studied Asian context, and form the basis from which future
426 research can be undertaken.

427 However, we acknowledge several limitations of our research. The magnitudes of some
428 associations discussed were small with wide 95% confidence intervals. Though our findings
429 provide early evidence on the possible associations between children's movement behaviours
430 and their HRQoL, the modest sample size and variability within our sample lends that
431 conclusions should be made with caution; future research is required to confirm our findings.
432 The use of accelerometry for movement data collection meant that information on the
433 context of activities such as location, type of activity (e.g., screen-viewing, organised sport,
434 active transport), and other dimensions of sleep which may have had important implications
435 on HRQoL could not be distinguished, undermining the associations (or lack thereof)
436 observed. While the KINDL-Kid questionnaire was previously validated in the local
437 context,^[38] it was recommended for only the overall and not domain-specific scores to be
438 interpreted as only the overall score demonstrated good internal consistency.
439 Notwithstanding, we presented both overall and domain-specific HRQoL scores to provide
440 insights on the potential associations between the movement behaviours and overall HRQoL
441 and specific HRQoL domains. We also recognise that the results centred around statistical
442 significance, which may not necessarily indicate minimally important difference.^[75]
443 However, as summarised in a review by Wu and colleagues, most studies to date only
444 reported statistical significance when reporting the relationship between movement
445 behaviours and HRQoL.^[10] The minimally important difference criterion differs by

446 instrument used to assess HRQoL, and such criteria were rarely applied in healthy
447 populations.^[10] In regard to HRQoL, we acknowledge that examining the various domains of
448 HRQoL as separate outcomes increases the risk of type 1 error due to multiple testing.
449 However, as our analyses were meant to be exploratory, we did not perform any correction
450 for multiple testing to not increase the risk of type 2 error. We also acknowledge that the
451 children of the GUSTO cohort were followed up at age 10 years in unique times that
452 coincided with the onset of the COVID-19 pandemic, which may have influenced our
453 findings. COVID-19 may have impacted children's HRQoL negatively such as increased
454 feelings of loneliness and isolation, wherein effects are disproportional for different social
455 groups (e.g., those of lower socio-economic positions).^[76,77] Further, the pandemic may also
456 impact children's movement behaviours through restrictions that vary over time (e.g. full
457 versus partial lockdown and the gradual transition towards endemic COVID-19).^[78] We
458 adjusted for this by accounting for whether the participants were followed up before or after
459 the onset of the pandemic, but this measure is limited in measuring behavioural changes
460 caused by the pandemic and we cannot rule out residual confounding. We also wish to
461 mention that although included and excluded participants of the present study did not differ
462 significantly in characteristics (Supplementary Table 1), the overall GUSTO cohort is not
463 representative of the Singapore population.^[30] hence our findings should be extrapolated to
464 the Singapore or other general population with caution.

465

466 **Conclusion**

467 Our study is novel in that it is, to our knowledge, the first that examined the cross-sectional
468 and prospective associations between the full movement spectrum of children and their
469 overall and domain-specific HRQoL, in the less studied Asian population. Generally, we
470 found that sleep and physical activity were positively associated with HRQoL, while
471 inactivity was negatively associated with HRQoL, though our findings also highlight the
472 complexity of these relationships. These findings contribute to existing literature on
473 children's movement behaviours and their HRQoL and form the basis from which future
474 research can be undertaken.

475

476 **Declarations**

477 *Author contributions*

478 Authorship: MF-FC and FMR designed the research; YSC, KMG, KHT, and JGE designed
479 and led the GUSTO study; JYT and NP conducted research and/or collected the GUSTO
480 data; SYXT performed the statistical analysis with guidance from JYB, CST, and FMR;
481 SYXT drafted the manuscript; NP, JYB, CST, MF-FC, and FMR critically reviewed the
482 manuscript; all authors read and approved the final manuscript.

483

484 *Funding*

485 This study is supported by the Singapore National Research Foundation under its
486 Translational and Clinical Research (TCR) Flagship Programme and administered by the
487 Singapore Ministry of Health's National Medical Research Council (NMRC), Singapore –
488 NMRC/TCR/004-NUS/2008; NMRC/TCR/012-NUHS/2014. Additional funding is provided
489 by the Singapore Institute for Clinical Sciences, Agency for Science Technology and
490 Research (A*STAR), Singapore. KMG is supported by the UK Medical Research Council
491 (MC_UU_12011/4), the National Institute for Health Research (NIHR Senior Investigator
492 (NF-SI-0515-10042) and NIHR Southampton Biomedical Research Centre (IS-BRC-1215-
493 20004)), the European Union (Erasmus+ Programme ImpENSA 598488-EPP-1-2018-1-DE-
494 EPPKA2-CBHE-JP) and the British Heart Foundation (RG/15/17/3174). For the purpose of
495 Open Access, the author has applied a Creative Commons Attribution (CC BY) licence to
496 any Author Accepted Manuscript version arising from this submission. JYB is supported by a
497 grant from the Agence Nationale de la Recherche (ANR) (iSCAN project, ANR-20-CE36-
498 0001). The funders had no role in the design of the study and collection, analysis, and
499 interpretation of data and in writing the manuscript.

500

501 *Declaration of interests*

502 KMG and Y-SC report reimbursement for speaking at conferences sponsored by Nestle
503 Nutrition Institute and are part of an academic consortium that has received research funding
504 from Abbott Nutrition, Nestle, and Danone. Y-SC also reports grants from Singapore
505 Ministry of Health's National Medical Research Council; research support from Singapore

506 Institute for Clinical Sciences, Agency for Science Technology and Research, during the
507 conduct of the study; has a patent Vitamin B12 and its use for gestational diabetes pending;
508 has a patent Myo-inositol and one or more probiotics for use in type 2 diabetes pending; has a
509 patent Vitamin B12 and for use in type 2 diabetes pending; and owns a patent for Myo-
510 inositol and one or more probiotics for gestational diabetes. All other authors declare no
511 competing interests.

512

513 *Acknowledgements*

514 The authors thank the participants of the GUSTO study, staff involved in the data collection
515 and management, and the GUSTO study group, which comprise the following members: Airu
516 Chia, Allan Sheppard, Amutha Chinnadurai, Anna Magdalena Fogel, Anne Eng Neo Goh,
517 Anne Hin Yee Chu, Anne Rifkin-Graboi, Anqi Qiu, Arijit Biswas, Bee Wah Lee, Birit
518 Froukje Philipp Broekman , Bobby Kyungbeom Cheon, Boon Long Quah, Candida Vaz,
519 Chai Kiat Chng, Cheryl Shufen Ngo, Choon Looi Bong, Christiani Jeyakumar Henry, Ciaran
520 Gerard Forde, Claudia Chi, Daniel Yam Thiam Goh, Dawn Xin Ping Koh, Desiree Y. Phua,
521 Doris Ngiuk Lan Loh, E Shyong Tai, Elaine Kwang Hsia Tham, Elaine Phaik Ling Quah,
522 Elizabeth Huiwen Tham, Evelyn Chung Ning Law, Evelyn Xiu Ling Loo, Fabian Kok Peng
523 Yap, Faidon Magkos, Falk Müller-Riemenschneider, George Seow Heong Yeo, Hannah Ee
524 Juen Yong, Helen Yu Chen, Heng Hao Tan, Hong Pan, Hugo P S van Bever, Hui Min Tan,
525 Iliana Magiati, Inez Bik Yun Wong, Ives Yubin Lim, Ivy Yee-Man Lau, Izzuddin Bin Mohd
526 Aris, Jeannie Tay, Jeevesh Kapur, Jenny L. Richmond, Jerry Kok Yen Chan, Jia Xu, Joanna
527 Dawn Holbrook, Joanne Su-Yin Yoong, Joao Nuno Andrade Requicha Ferreira, Johan
528 Gunnar Eriksson, Jonathan Tze Liang Choo, Jonathan Y. Bernard, Jonathan Yinhao Huang,
529 Joshua J. Gooley, Jun Shi Lai, Karen Mei Ling Tan, Keith M. Godfrey, Kenneth Yung
530 Chiang Kwek, Keri McCrickerd, Kok Hian Tan, Kothandaraman Narasimhan,
531 Krishnamoorthy Naiduvaje, Kuan Jin Lee, Leher Singh, Li Chen, Lieng Hsi Ling, Lin Lin Su,
532 Ling-Wei Chen, Lourdes Mary Daniel, Lynette Pei-Chi Shek, Marielle V. Fortier, Mark
533 Hanson, Mary Foong-Fong Chong, Mary Rauff, Mei Chien Chua, Melvin Khee-Shing Leow,
534 Michael J. Meaney, Michelle Zhi Ling Kee, Min Gong, Mya Thway Tint, Navin Michael,
535 Neerja Karnani, Ngee Lek, Oon Hoe Teoh, P. C. Wong, Paulin Tay Straughan, Peter David
536 Gluckman, Pratibha Keshav Agarwal, Priti Mishra, Queenie Ling Jun Li, Rob Martinus van
537 Dam, Salome A. Rebello, Sambasivam Sendhil Velan, Seang Mei Saw, See Ling Loy, Seng

538 Bin Ang, Shang Chee Chong, Sharon Ng, Shiao-Yng Chan, Shirong Cai, Shu-E Soh, Sok
539 Bee Lim, Stella Tsotsi, Stephen Chin-Ying Hsu , Sue-Anne Ee Shiow Toh, Suresh Anand
540 Sadananthan, Swee Chye Quek, Varsha Gupta, Victor Samuel Rajadurai, Walter Stunkel,
541 Wayne Cutfield, Wee Meng Han, Wei Wei Pang, Wen Lun Yuan, Yanan Zhu, Yap Seng
542 Chong, Yin Bun Cheung, Yiong Huak Chan, and Yung Seng Lee.

References

1. World Health Organization. Constitution of the World Health Organization. 2006.
2. Matza LS, Swensen AR, Flood EM, Secnik K, Leidy NK. Assessment of health-related quality of life in children: a review of conceptual, methodological, and regulatory issues. *Value in health*. 2004;7(1):79-92.
3. World Health Organization. Sustainable Development Goals [Available from: https://www.who.int/health-topics/sustainable-development-goals#tab=tab_1].
4. Centers for Disease Control and Prevention. HRQOL Concepts 2016 [Available from: <https://www.cdc.gov/hrqol/concept.htm>].
5. Phyo AZZ, Freak-Poli R, Craig H, Gasevic D, Stocks NP, Gonzalez-Chica DA, et al. Quality of life and mortality in the general population: a systematic review and meta-analysis. *BMC public health*. 2020;20:1-20.
6. Health Promotion Board. NurtureSG Action Plan Report [Available from: https://www.hpb.gov.sg/docs/default-source/default-document-library/nurturesg-action-plan-report.pdf?sfvrsn=460f572_0].
7. Meyer M, Oberhoffer R, Hock J, Giegerich T, Müller J. Health-related quality of life in children and adolescents: Current normative data, determinants and reliability on proxy-report. *Journal of paediatrics and child health*. 2016;52(6):628-31.

8. Ng TP, Lim LCC, Jin A, Shinfuku N. Ethnic differences in quality of life in adolescents among Chinese, Malay and Indians in Singapore. *Quality of Life Research*. 2005;14(7):1755-68.
9. Bolton K, Kremer P, Rossthorn N, Moodie M, Gibbs L, Waters E, et al. The effect of gender and age on the association between weight status and health-related quality of life in Australian adolescents. *BMC Public Health*. 2014;14(1):1-8.
10. Wu XY, Han LH, Zhang JH, Luo S, Hu JW, Sun K. The influence of physical activity, sedentary behavior on health-related quality of life among the general population of children and adolescents: A systematic review. *PloS one*. 2017;12(11):e0187668.
11. Dumuid D, Maher C, Lewis LK, Stanford TE, Fernández JAM, Ratcliffe J, et al. Human development index, children's health-related quality of life and movement behaviors: a compositional data analysis. *Quality of Life Research*. 2018;27(6):1473-82.
12. Lubans D, Richards J, Hillman C, Faulkner G, Beauchamp M, Nilsson M, et al. Physical activity for cognitive and mental health in youth: a systematic review of mechanisms. *Pediatrics*. 2016;138(3).
13. Marker AM, Steele RG, Noser AE. Physical activity and health-related quality of life in children and adolescents: A systematic review and meta-analysis. *Health Psychology*. 2018;37(10):893.
14. Short MA, Bartel K, Carskadon MA. Sleep and mental health in children and adolescents. *Sleep and health: Elsevier*; 2019. p. 435-45.
15. Gregory AM, Sadeh A. Sleep, emotional and behavioral difficulties in children and adolescents. *Sleep medicine reviews*. 2012;16(2):129-36.
16. Sampasa-Kanyinga H, Standage M, Tremblay MS, Katzmarzyk PT, Hu G, Kuriyan R, et al. Associations between meeting combinations of 24-h movement guidelines and health-related quality of life in children from 12 countries. *Public Health*. 2017;153:16-24.
17. Haerens L, Vereecken C, Maes L, De Bourdeaudhuij I. Relationship of physical activity and dietary habits with body mass

index in the transition from childhood to adolescence: a 4-year longitudinal study. *Public Health Nutrition*. 2010;13(10A):1722-8.

18. Leech R, McNaughton S, Timperio A. Clustering of diet, physical activity and sedentary behaviour among Australian children: cross-sectional and longitudinal associations with overweight and obesity. *International journal of obesity*. 2015;39(7):1079-85.

19. Corder K, Sharp SJ, Atkin AJ, Griffin SJ, Jones AP, Ekelund U, et al. Change in objectively measured physical activity during the transition to adolescence. *British journal of sports medicine*. 2015;49(11):730-6.

20. Thomas G, Bennie JA, De Cocker K, Ireland MJ, Biddle SJ. Screen-based behaviors in Australian adolescents: Longitudinal trends from a 4-year follow-up study. *Preventive Medicine*. 2020;141:106258.

21. Belmon LS, van Stralen MM, Busch V, Harmsen IA, Chinapaw MJ. What are the determinants of children's sleep behavior? A systematic review of longitudinal studies. *Sleep medicine reviews*. 2019;43:60-70.

22. Spear HJ, Kulbok P. Autonomy and adolescence: A concept analysis. *Public Health Nursing*. 2004;21(2):144-52.

23. Padmapriya N, Chen B, Goh CMJL, Shek LPC, Chong YS, Tan KH, et al. 24-hour movement behaviour profiles and their transition in children aged 5.5 and 8 years—findings from a prospective cohort study. *International Journal of Behavioral Nutrition and Physical Activity*. 2021;18(1):1-14.

24. Khan A, Lee EY, Tremblay MS. Meeting 24-h movement guidelines and associations with health related quality of life of Australian adolescents. *J Sci Med Sport*. 2021;24(5):468-73.

25. Dumuid D, Pedišić Ž, Palarea-Albaladejo J, Martín-Fernández JA, Hron K, Olds T. Compositional Data Analysis in Time-Use Epidemiology: What, Why, How. *Int J Environ Res Public Health*. 2020;17(7).

26. Pedišić Ž, Dumuid D, S Olds T. Integrating sleep, sedentary behaviour, and physical activity research in the emerging field of

time-use epidemiology: definitions, concepts, statistical methods, theoretical framework, and future directions. *Kinesiology: International journal of fundamental and applied kinesiology*. 2017;49(2.):252-69.

27. Tsiros MD, Samaras MG, Coates AM, Olds T. Use-of-time and health-related quality of life in 10-to 13-year-old children: not all screen time or physical activity minutes are the same. *Quality of Life Research*. 2017;26(11):3119-29.

28. Rees G, Dinisman T. Comparing children's experiences and evaluations of their lives in 11 different countries. *Child Indicators Research*. 2015;8(1):5-31.

29. Rapley M. *Quality of life research: A critical introduction*: Sage; 2003.

30. Soh S-E, Tint MT, Gluckman PD, Godfrey KM, Rifkin-Graboi A, Chan YH, et al. Cohort profile: Growing Up in Singapore Towards healthy Outcomes (GUSTO) birth cohort study. *International journal of epidemiology*. 2014;43(5):1401-9.

31. Health Promotion Board. *Body Mass Index (BMI)-for-Age - Children and Youth Aged 6 to 18 Years Old*.

32. Tan SYX, Chia A, Tai BC, Natarajan P, Goh CMJL, Shek LP, et al. A Web-Based, Time-Use App To Assess Children's Movement Behaviors: Validation Study of My E-Diary for Activities and Lifestyle (MEDAL). *JMIR Pediatrics and Parenting*. 2022;5(2):e33312.

33. Sabia SP, Cogranne PB, van Hees VTP, Bell JAM, Elbaz AMDP, Kivimaki MP, et al. Physical Activity and Adiposity Markers at Older Ages: Accelerometer Vs Questionnaire Data. *Journal of the American Medical Directors Association*. 2015;16(5):438.e7-.e13.

34. van Hees VT, Sabia S, Anderson KN, Denton SJ, Oliver J, Catt M, et al. A Novel, Open Access Method to Assess Sleep Duration Using a Wrist-Worn Accelerometer. *PLoS One*. 2015;10(11):e0142533.

35. Hildebrand M, VT VANH, Hansen BH, Ekelund U. Age group comparability of raw accelerometer output from wrist- and hip-worn monitors. *Med Sci Sports Exerc.* 2014;46(9):1816-24.
36. Hildebrand M, Hansen BH, van Hees VT, Ekelund U. Evaluation of raw acceleration sedentary thresholds in children and adults. *Scand J Med Sci Sports.* 2017;27(12):1814-23.
37. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary behavior research network (SBRN)–terminology consensus project process and outcome. *International Journal of Behavioral Nutrition and Physical Activity.* 2017;14(1):75.
38. Wee H-L, Ravens-Sieberer U, Erhart M, Li S-C. Factor structure of the Singapore English version of the KINDL® children quality of life questionnaire. *Health and Quality of Life Outcomes.* 2007;5(1):1-8.
39. Dumuid D, Stanford TE, Martín-Fernández J-A, Pedišić Ž, Maher CA, Lewis LK, et al. Compositional data analysis for physical activity, sedentary time and sleep research. *Statistical methods in medical research.* 2018;27(12):3726-38.
40. Egozcue JJ, Pawłowsky-Glahn V. Groups of parts and their balances in compositional data analysis. *Mathematical Geology.* 2005;37(7):795-828.
41. Dumuid D, Stanford TE, Pedišić Ž, Maher C, Lewis LK, Martín-Fernández J-A, et al. Adiposity and the isothermal substitution of physical activity, sedentary time and sleep among school-aged children: a compositional data analysis approach. *BMC public health.* 2018;18(1):1-10.
42. Van den Boogaart KG, Tolosana-Delgado R. “Compositions”: a unified R package to analyze compositional data. *Computers & Geosciences.* 2008;34(4):320-38.
43. Templ M, Hron K, Filzmoser P. robCompositions: an R-package for robust statistical analysis of compositional data. *Compositional data analysis: Theory and applications.* 2011:341-55.

44. Hothorn T, Zeileis A, Farebrother RW, Cummins C, Millo G, Mitchell D, et al. Package 'lmtest'. Testing linear regression models <https://cran.r-project.org/web/packages/lmtest/lmtest.pdf> Accessed. 2015;6.
45. Fox J. Car: companion to applied regression. R package version 1.2-16. <http://CRAN.R-project.org/package=car>. 2009.
46. Carson V, Tremblay MS, Chaput J-P, Chastin SF. Associations between sleep duration, sedentary time, physical activity, and health indicators among Canadian children and youth using compositional analyses. *Applied Physiology, Nutrition, and Metabolism*. 2016;41(6):S294-S302.
47. Aubert S, Barnes JD, Abdeta C, Abi Nader P, Adeniyi AF, Aguilar-Farias N, et al. Global matrix 3.0 physical activity report card grades for children and youth: results and analysis from 49 countries. *Journal of physical activity and health*. 2018;15(s2):S251-S73.
48. Müller AM, Khoo S, Lambert R. Review of physical activity prevalence of Asian school-age children and adolescents. *Asia Pac J Public Health*. 2013;25(3):227-38.
49. Dale LP, Vanderloo L, Moore S, Faulkner G. Physical activity and depression, anxiety, and self-esteem in children and youth: An umbrella systematic review. *Mental Health and Physical Activity*. 2019;16:66-79.
50. Liu M, Wu L, Ming Q. How does physical activity intervention improve self-esteem and self-concept in children and adolescents? Evidence from a meta-analysis. *PloS one*. 2015;10(8):e0134804.
51. Ekeland E, Heian F, Hagen KB. Can exercise improve self esteem in children and young people? A systematic review of randomised controlled trials. *British journal of sports medicine*. 2005;39(11):792-8.
52. Howie LD, Lukacs SL, Pastor PN, Reuben CA, Mendola P. Participation in activities outside of school hours in relation to problem behavior and social skills in middle childhood. *Journal of school Health*. 2010;80(3):119-25.

53. Barber BL, Eccles JS, Stone MR. Whatever happened to the jock, the brain, and the princess? Young adult pathways linked to adolescent activity involvement and social identity. *Journal of adolescent research*. 2001;16(5):429-55.
54. Boone EM, Leadbeater BJ. Game on: Diminishing risks for depressive symptoms in early adolescence through positive involvement in team sports. *Journal of Research on Adolescence*. 2006;16(1):79-90.
55. Eime RM, Young JA, Harvey JT, Charity MJ, Payne WR. A systematic review of the psychological and social benefits of participation in sport for children and adolescents: informing development of a conceptual model of health through sport. *International journal of behavioral nutrition and physical activity*. 2013;10(1):1-21.
56. Omorou AY, Langlois J, Lecomte E, Briançon S, Vuillemin A. Cumulative and bidirectional association of physical activity and sedentary behaviour with health-related quality of life in adolescents. *Quality of life Research*. 2016;25:1169-78.
57. Medic G, Wille M, Hemels ME. Short-and long-term health consequences of sleep disruption. *Nature and science of sleep*. 2017;9:151.
58. Dewald JF, Meijer AM, Oort FJ, Kerkhof GA, Bögels SM. The influence of sleep quality, sleep duration and sleepiness on school performance in children and adolescents: A meta-analytic review. *Sleep medicine reviews*. 2010;14(3):179-89.
59. Chaput J-P, Gray CE, Poitras VJ, Carson V, Gruber R, Olds T, et al. Systematic review of the relationships between sleep duration and health indicators in school-aged children and youth. *Applied physiology, nutrition, and metabolism*. 2016;41(6):S266-S82.
60. Jalali-Farahani S, Amiri P, Chin YS. Are physical activity, sedentary behaviors and sleep duration associated with body mass index-for-age and health-related quality of life among high school boys and girls? *Health Qual Life Outcomes*. 2016;14:30.

61. Jarrin DC, McGrath JJ, Drake CL. Beyond sleep duration: distinct sleep dimensions are associated with obesity in children and adolescents. *International journal of obesity*. 2013;37(4):552-8.
62. Butte NF, Watson KB, Ridley K, Zakeri IF, McMurray RG, Pfeiffer KA, et al. A Youth Compendium of Physical Activities: Activity Codes and Metabolic Intensities. *Med Sci Sports Exerc*. 2018;50(2):246-56.
63. Finne E, Bucksch J, Lampert T, Kolip P. Physical activity and screen-based media use: cross-sectional associations with health-related quality of life and the role of body satisfaction in a representative sample of German adolescents. *Health Psychology and Behavioral Medicine: An Open Access Journal*. 2013;1(1):15-30.
64. Gopinath B, Louie JC, Flood VM, Burlutsky G, Hardy LL, Baur LA, et al. Influence of obesogenic behaviors on health-related quality of life in adolescents. *Asia Pacific Journal of Clinical Nutrition*. 2014;23(1):121-7.
65. Gopinath B, Hardy LL, Baur LA, Burlutsky G, Mitchell P. Physical activity and sedentary behaviors and health-related quality of life in adolescents. *Pediatrics*. 2012;130(1):e167-e74.
66. Chen X, Sekine M, Hamanishi S, Yamagami T, Kagamimori S. Associations of lifestyle factors with quality of life (QOL) in Japanese children: a 3-year follow-up of the Toyama Birth Cohort Study. *Child: care, health and development*. 2005;31(4):433-9.
67. Mireku MO, Barker MM, Mutz J, Dumontheil I, Thomas MS, Rösli M, et al. Night-time screen-based media device use and adolescents' sleep and health-related quality of life. *Environment international*. 2019;124:66-78.
68. Penedo FJ, Dahn JR. Exercise and well-being: a review of mental and physical health benefits associated with physical activity. *Current opinion in psychiatry*. 2005;18(2):189-93.
69. Marquez DX, Aguiñaga S, Vásquez PM, Conroy DE, Erickson KI, Hillman C, et al. A systematic review of physical activity and quality of life and well-being. *Translational behavioral medicine*. 2020;10(5):1098-109.

70. Perkinson-Gloor N, Lemola S, Grob A. Sleep duration, positive attitude toward life, and academic achievement: the role of daytime tiredness, behavioral persistence, and school start times. *Journal of adolescence*. 2013;36(2):311-8.
71. Do YK, Shin E, Bautista MA, Foo K. The associations between self-reported sleep duration and adolescent health outcomes: what is the role of time spent on Internet use? *Sleep medicine*. 2013;14(2):195-200.
72. Johnson DA, Billings ME, Hale L. Environmental determinants of insufficient sleep and sleep disorders: implications for population health. *Current epidemiology reports*. 2018;5(2):61-9.
73. Tu KM, Marks BT, El-Sheikh M. Sleep and mental health: the moderating role of perceived adolescent-parent attachment. *Sleep Health*. 2017;3(2):90-7.
74. Zhang T, Lu G, Wu XY. Associations between physical activity, sedentary behaviour and self-rated health among the general population of children and adolescents: a systematic review and meta-analysis. *BMC Public Health*. 2020;20(1):1-16.
75. Cella D, Bullinger M, Scott C, Barofsky I. Group vs individual approaches to understanding the clinical significance of differences or changes in quality of life. *Mayo Clin Proc*. 2002;77(4):384-92.
76. Nobari H, Fashi M, Eskandari A, Villafaina S, Murillo-Garcia Á, Pérez-Gómez J. Effect of COVID-19 on health-related quality of life in adolescents and children: A systematic review. *International Journal of Environmental Research and Public Health*. 2021;18(9):4563.
77. Ahn SN. The Potential Impact of COVID-19 on Health-Related Quality of Life in Children and Adolescents: A Systematic Review. *International Journal of Environmental Research and Public Health*. 2022;19(22):14740.
78. Paterson DC, Ramage K, Moore SA, Riazi N, Tremblay MS, Faulkner G. Exploring the impact of COVID-19 on the movement behaviors of children and youth: A scoping review of evidence after the first year. *Journal of sport and health science*. 2021.

