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HAL Authorization

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**

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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.

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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,<sup>[1,2]</sup> has been gaining traction.<sup>[3]</sup>  
65 Being a strong predictor of morbidity and mortality,<sup>[4,5]</sup> 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.<sup>[6]</sup> Concerningly, HRQoL of  
68 children in various countries was observed to decline with age;<sup>[7-9]</sup> in Singapore, this decline  
69 was observed to occur from the age of 10 years.<sup>[8]</sup>

70 While this decline may be attributed to lesser leisure time, increased academic pressure, and  
71 the transition into puberty as children grow older,<sup>[7]</sup> 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.<sup>[10]</sup> 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<sup>[11-13]</sup>. Sleep on the other hand was associated with mood and emotional regulation<sup>[14,15]</sup>  
78 wherein inadequate sleep was associated with poorer HRQoL among children aged 9 to 11  
79 years.<sup>[16]</sup> Though the mechanisms of inactivity on HRQoL were less explored,<sup>[10]</sup> it is  
80 postulated that time spent in inactivity may displace physical activity and/or sleep, explaining  
81 the negative associations with HRQoL.<sup>[10]</sup>

82 As children grow older and gain autonomy over their lifestyle aspects, they become less  
83 physically active and increasingly sedentary.<sup>[17-22]</sup> 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.<sup>[23]</sup> 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.<sup>[16,24]</sup>

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,<sup>[10]</sup> resulting in inaccurate estimates of association.<sup>[25,26]</sup> 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.<sup>[10,11,27]</sup> HRQoL  
97 research in children have also been concentrated in Western contexts, with limited  
98 representation of Asian populations.<sup>[11,27]</sup> Since perception of HRQoL reflects one's life  
99 experiences<sup>[28]</sup> which could depend on political, social, economic, and environmental  
100 contexts,<sup>[29]</sup> 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.<sup>[30]</sup> 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 m<sup>2</sup>) and  
134 classified as underweight, normal weight, and overweight based on age- and sex-specific cut-  
135 offs for Singaporean children <sup>[31]</sup>. 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.<sup>[32]</sup>  
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.<sup>[33]</sup> 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.<sup>[34-36]</sup> For the present study,  
160 inactivity was used as proxy for sedentary behaviour (defined as activities “ $\leq 1.5$  metabolic  
161 equivalents while in a sitting, reclining or lying posture”<sup>[37]</sup>) 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.<sup>[38]</sup> 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<sup>[26]</sup> based on previously developed methods by Dumuid  
183 and colleagues for epidemiological research.<sup>[39]</sup> 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,<sup>[40]</sup> 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.<sup>[25]</sup> This coordinate therefore contains information  
188 regarding one movement behaviour as a variable relative to the other three behaviours.<sup>[39]</sup> 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.<sup>[39]</sup> 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.<sup>[41]</sup>  
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,<sup>[42]</sup>  
213 robCompositions,<sup>[43]</sup> lmtree,<sup>[44]</sup> and car<sup>[45]</sup> 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

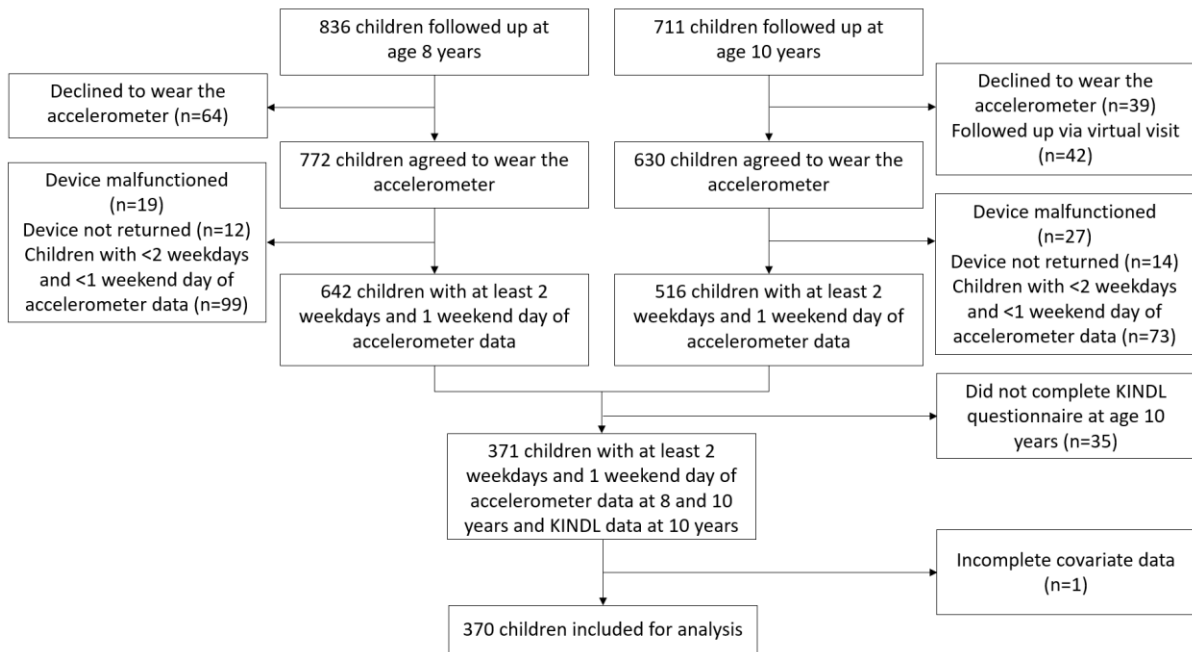
## 220 **Results**

### 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

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

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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

		<b>Overall HRQoL</b>	<b>Physical well-being</b>	<b>Emotional well-being</b>	<b>Self-esteem</b>	<b>Relationship with family</b>	<b>Relationship with friends</b>	<b>School functioning</b>
<b>Sleep</b>	<b>10 years</b>	-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)
	<b>8 years</b>	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)
<b>Inactivity</b>	<b>10 years</b>	-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)
	<b>8 years</b>	-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)*
<b>LPA</b>	<b>10 years</b>	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)
	<b>8 years</b>	-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)
<b>MVPA</b>	<b>10 years</b>	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)
	<b>8 years</b>	-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  $\beta$  (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)

	<b>Overall HRQoL</b>	<b>Physical well-being</b>	<b>Emotional well-being</b>	<b>Self-esteem</b>	<b>Relationship with family</b>	<b>Relationship with friends</b>	<b>School functioning</b>
<b>Increase sleep</b>							
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)
<b>Increase inactivity</b>							
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)

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

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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  $\beta$  (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)

	<b>Overall HRQoL</b>	<b>Physical well-being</b>	<b>Emotional well-being</b>	<b>Self-esteem</b>	<b>Relationship with family</b>	<b>Relationship with friends</b>	<b>School functioning</b>
<b>Increase sleep</b>							
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)
<b>Increase inactivity</b>							
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, 5.10)	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)
<b>Increase LPA</b>							
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)
<b>Increase MVPA</b>							
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  $\beta$  (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,<sup>[11,46]</sup> which may be attributed to  
306 already suboptimal MVPA durations in children,<sup>[47,48]</sup> 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)<sup>[49-51]</sup> 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).<sup>[12]</sup> Physical activity also provides opportunities for socialisation,<sup>[12]</sup>  
314 promotes social skills,<sup>[52]</sup> reduces feelings of social isolation,<sup>[53]</sup> and increases perceived  
315 social acceptance,<sup>[54]</sup> all of which are associated with better psychosocial outcomes including  
316 social relationships.<sup>[55]</sup> 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.<sup>[56]</sup>

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.<sup>[14,15,57-59]</sup> 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,<sup>[11,27,60]</sup> warranting future studies to examine the role of these  
343 dimensions in children's HRQoL more deeply.<sup>[61]</sup>

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.<sup>[62]</sup> 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,<sup>[10]</sup> cross-sectionally<sup>[63]</sup>  
350 and prospectively.<sup>[56,64-66]</sup> Further, night-time screen-viewing has been negatively associated  
351 with sleep and HRQoL among children.<sup>[67]</sup> 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.<sup>[12,68]</sup> However, findings on associations  
365 between physical activity and HRQoL have been equivocal, with some studies demonstrating  
366 a positive association and others none.<sup>[10,13,69]</sup> 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.<sup>[13]</sup> 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,<sup>[70,71]</sup> 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.<sup>[59]</sup> 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,<sup>[72]</sup> while secure parent-child relationships were associated with better sleep.<sup>[73]</sup> 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).<sup>[23]</sup> 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,<sup>[10,74]</sup> 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<sup>[25]</sup>  
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.<sup>[8]</sup> Previous studies examining the relationship between HRQoL and  
404 movement behaviours of children were largely conducted in homogenous samples.<sup>[11,27]</sup> 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.<sup>[8]</sup> 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.<sup>[11,39]</sup> 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,<sup>[38]</sup> 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.<sup>[75]</sup>  
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.<sup>[10]</sup> The minimally important difference criterion differs by

446 instrument used to assess HRQoL, and such criteria were rarely applied in healthy  
447 populations.<sup>[10]</sup> 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).<sup>[76,77]</sup> 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).<sup>[78]</sup> 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.<sup>[30]</sup> 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.

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500

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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-  
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