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Article

Impact of COVID-19 Pandemic on School-aged Children's Physical Activity, Screen Time and Sleep in Hong Kong: a Cross-sectional Repeated Measures Study

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Abstract: Despite concerns about the negative effects of social distancing and prolonged school closures on children's lifestyle and physical activity (PA) during the COVID-19 pandemic, robust evidence is lacking on the impact of the COVID-19 pandemic on children's wellbeing and daily life. This study aimed to examine changes in the PA levels, sleep patterns and screen time of school-aged children during the different phases of COVID-19 outbreak in Hong Kong using a repeated cross-sectional design. School students (Grades 1 to 12) were asked to report their daily electronic device usage and to fill in a sleep dairy recording their daily sleep and wake-up time. They were equipped with a PA monitor, Actigraph wGT3X-BT, to obtain objective data on their PA levels and sleep patterns. Students were recruited before the pandemic (Sep 2019 – Jan 2020; n=577), during school closures (Mar 2020 – Apr 2020; n=146), and after schools partially reopened (Oct 2020 – Jul 2021; n=227). Our results indicated lower PA levels, longer sleep duration, and longer screen time among participants recruited during school closures than those recruited before the COVID-19 outbreak. Primary school students were found to sleep on average for an extra hour during school closures. Our findings illustrate the impact of social distancing policies during the COVID-19 pandemic on the sleep pattern, screen time, and PA level in school-aged children in Hong Kong. Professionals should reinforce the importance of maintaining a physically active lifestyle, good sleep hygiene, and healthy use of electronic devices to parents and school-aged children during the COVID-19 Pandemic.

Keywords: COVID-19 pandemic; school closures; school-aged children; physical activity; screen time; sleep; Hong Kong

1. Introduction

During the coronavirus disease 2019 (COVID-19) pandemic, social distancing policies such as home confinement and school closures, , as well as very limited/no outdoor play for school children, resulted in a variety of lifestyle changes in children and adolescents [1]. It has been proposed that the lockdown measures have affected the general well-

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being and lifestyle of children and adolescents more profoundly than the infection itself [2]. Since the outbreak, there has been increasing research interests on the impact of these policies on physical activity (PA), screen time, and sleep patterns among children and adolescents. According to a study in Shanghai, the prevalence of physically inactive school-aged children increased from 21% in January 2020 to 66% in March 2020 [3]. However, countries such as Colombia, Spain, Italy, and Germany observed an increase in PA during the pandemic [4;5], whereas five studies found no significant differences in PA behavior before and during the pandemic [5-7]. The status, intensity, and duration of COVID-19 restrictions have varied by country and region, which may potentially explain the inter-regional differences in children's PA during the pandemic [8]. A recent report in the US showed that the non-academic screen time of children doubled during the COVID-19 pandemic from 3.8 to 7.7 hours a day [9].This raises concerns about the potential harms of excessive screen time, such as the risks to physical and mental health, such as greater obesity and higher depressive symptoms, among school-aged children [10]. In addition, evidence showed that school-aged children had longer sleep duration, with delayed sleep onset and wake-up times as a result of homeschooling during this period [8;11;12]. Although adequate sleep is beneficial for children, researchers found a pooled prevalence of sleep disturbances of up to 54% in children during the pandemic [13]. Some researchers have suggested that the COVID-19 pandemic could have exacerbated existing lifestyle problems such as physical inactivity and sedentary lifestyles due to missed PA classes and social distancing measures [14].

However, the majority of evidence in the current literature is limited, as it is mainly based on subjective questionnaire assessments and only looked at the short-term changes across the first year of the pandemic. It would be meaningful to examine the longer-term impact of the pandemic on the lifestyles of children and adolescents. Although the association between lifestyle and well-being in school-aged children is widely studied, studies using objective assessments are needed to generate robust evidence on the effects of the COVID-19 pandemic on school-aged children's lifestyle such as physical activity and sleep patterns. To the best of our knowledge, only one study has used actigraph data to evaluate sleep patterns in 16 healthy Japanese preschoolers during the pandemic [15]. In this study, we objectively measured and compared lifestyle habits including PA levels, sleep patterns, and screen time in school-aged children in Hong Kong during the different phases of the COVID-19 outbreak in order to examine the impact of policy on schooling on children during pandemic.

2. Materials and Methods

This was a repeated cross-sectional study [16] designed to assess the impact of COVID-19 on school-aged children in Hong Kong over 2 years across three time-points including pre-pandemic (Sep 2019 – Jan 2020), school closures (Mar 2020 – Apr 2020), and partial school reopening (Oct 2020 – Jul 2021). We explored changes in PA levels, sleep patterns, and electronic device usage (screen time) in primary and secondary school students. Repeated cross-sectional designs assess independent samples in each time period, which can allow meaningful inference of changes across a population. Although overlap of cross-sectional samples is advantageous because it minimizes the variance of parameter estimates, considerable sample overlap is not required for reliable conclusions regarding population trends over time [17].

2.1. Participants

The study sample was divided into the five main districts of Hong Kong – Hong Kong Island, West Kowloon, East Kowloon, West New Territories, and East New Territories. Using a stratified random sampling method, a list of primary (grade 1-6) and secondary (grade 7-12) schools from each district was randomly generated. The primary and secondary schools in each district were invited to participate according to the list. If the invitation was rejected, the next school on the list was invited until the required sample size

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was met. One grade of students was randomly selected from each school to participate. This method has been adopted in our previous local prevalence study published in a peer-reviewed journal [18].

The first assessment was conducted between September 2019 and January 2020 before the first wave of the COVID-19 outbreak in Hong Kong. Schools that agreed to participate in the study were contacted by mail and telephone. Written informed consent was obtained from the participants' parents. Each pair of student and parent received a set of questionnaires and an activity monitor (Actigraph wGT3X-BT, Pensacola, Florida, USA). The Actigraph device has been used to monitor PA and sleep in children in several peer-reviewed publications [19-22].

The second assessment was conducted between late February and March 2020, approximately two months after school closures due to the first wave of COVID-19 in Hong Kong. Parents willing to participate in the assessments were contacted by telephone. A set of questionnaires and an Actigraph device were delivered to each participating household. To comply with the social-distancing policies and to minimize infection risk, the consent form, questionnaire, and Actigraph device were left by the door of each household. The signed consent forms, questionnaires, and PA monitoring device were collected at the end of the monitoring period.

The third assessment was conducted between October 2020 and July 2021 after schools were partially reopened. Students were required to attend half-day in-person classes at school and then half-day online lessons at home. Participating schools were contacted by mail and phone. After the signed consent form was returned, the questionnaire and Actigraph set was distributed to students and parents.

2.2. Measurements

2.2.1. Questionnaires

The questionnaires were completed by one parent of the student. Demographic information and data on children's electronic device usage (screen time) [23] were collected. Participants were also asked to fill in a sleep diary daily to record their sleep and wake-up times.

2.2.2. Screen time

Screen time was assessed by asking participants how many hours on average they spent using an electronic device (e.g., TV, online/electronic game, smartphone, computer, tablet) on a weekday and at the weekend. The electronic device usage was calculated using the weighted average formula: [(weekday*5) + (weekend*2)]/7.

2.2.3. Actigraph data

2.2.3.1. Non-wear time

The non-wear period was identified using the Choi algorithm [24]. A minimum of 90 consecutive "zero" epochs with a spike tolerance of 2 minutes and 100 counts/minute were used to identify non-wear periods. To properly analyze physical activity, subjects were required to have three valid monitoring days. One day's recording with more than 10 hours wear time beyond the sleep period was counted as a valid day [25]. Subjects with data from at least two days and nights were used in the sleep analysis.

2.2.3.2. Sleep measurements

2.2.3.2.1. Sleep period classification

Data were extracted and analyzed by using 60-second (1 minute) epochs. Each 1-minute epoch was classified as asleep or awake using the Cole-Kripke algorithm, which is very sensitive for detecting sleep using a wrist monitor. The Cole-Kripke algorithm adjusts the epoch data by rescaling the count values by 100 and setting values over 300 to 300 [26]. A sleep index less than 1 was classified as asleep and otherwise as awake [27]. Sleep periods were detected using the Tudor-Locke algorithm [25]. Bedtime was determined by five consecutive asleep minutes, whereas wake time was determined by 10

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consecutive awake minutes. Sleep periods beyond the sleep time and wake-up time marked in the students' sleep diary or over 50% non-wear time were eliminated.

2.2.3.2.2. Sleep parameters

The measurement of sleep-related parameters was based on previously described studies [20;28]. Parameters included sleep time and wake-up time, total sleep duration, latency, sleep efficiency, and sleep fragmentation index (SFI). Sleep efficiency was calculated as the percentage of asleep time divided by the total in-bed time. The SFI indicates restlessness during the sleep period [29] and was calculated as a sum of the movement index and the fragmentation index. The movement index was the percentage of total awake minutes out of the total in-bed time, whereas the fragmentation index was the percentage of one-minute periods of sleep over the entire sleep period. Latency was defined as the difference between the students' self-reported sleep time and accelerometer-detected sleep time.

2.2.3.2.3. Physical Activity Levels

Step count and sum of the vector magnitude (VM) in 60-second epochs were processed using ActiLife software version 6.13.4. Cut-offs for PA and sedentary behavior according to Chandler et al. were used to quantify the time spent as sedentary (VM <3672 per min), engaged in light PA (3672 <= VM per min <9816), moderate PA (9816 <= VM per min <23628), and moderate-to-vigorous PA (MVPA) (VM per min >= 23628) [30].

2.3. Statistical analysis

All analyses were conducted using R statistical software, version 4.0.3 (R Program for Statistical Computing). Principal Component Analysis was used to construct the socioeconomic status (SES) index using household income, parental education level, and occupation. Descriptive analyses were used to compare the demographic characteristics of the students among the three periods. A mixed effect model was used to compare the measurement variables of lifestyle (physical activity, sleep, and electronic device usage) among the three periods, adjusting for age, sex and SES status, for the whole sample and separately for primary and secondary schools.

Compositional data analysis (CoDA) was conducted using "compositions" and "robCompositions" r packages to explore the relationship between daily use of time (sleep, MVPA, screen time, and other activities) and sleep quality of children among the three periods. Small non-zero values were used in the imputation to replace zeros, as log ratios cannot be created with zero values [31]. Compositional isotemporal substitution analyses were performed to explore the influence of the reallocation of fixed time durations (15 min) between daily time use of different activities on children's sleep quality using SFI as the dependent variable. All models were adjusted for sex and SES status. Statistical significance was set at a two-sided $p < 0.05$ for all analyses.

2.4. Ethics

This study was approval by The Institutional Review Board of the University of Hong Kong / Hospital Authority Hong Kong West Cluster (IRB number: UW 19-516). Informed written consent was obtained from the parents of the participants.

3. Results

3.1. Descriptive analysis (Table 1)

A total of 577 students (267 Primary and 310 Secondary students) were recruited before the pandemic (Sep 2019 – Jan 2020), 146 students (87 Primary and 59 Secondary students) were recruited during school closures (Mar 2020 – Apr 2020), and 293 students (137 Primary and 156 Secondary students) were recruited after schools partially reopened (Oct 2020 – Jul 2021). Table 1 shows a summary of the participant baseline characteristics. There were no significant differences in students' anthropometric parameters or SES index among the three periods. The proportion of primary school students recruited during school closures was higher (60% during school closures vs 46% before pandemic and 47%

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after school reopened, p= 0.013), as well as the proportions of female students recruited during school closures and reopened were higher (68% during school closures and 77% after school reopened vs 58% before pandemic, p<0.001). Students recruited during the pre-pandemic period were slightly older than those in the other two periods (12.85 years old before the pandemic vs. 12.14 years during school closures, p = 0.006; 12.85 years before the pandemic vs. 11.93 years after schools partially reopened, p <0.001).

Table 1. Characteristics of the participants at 3 time-points.

	Pre-pandemic	During School Closure	School Partially Reopened	
Data collection period	Sep 2019 – Jan 2020	Mar 2020 – Apr 2020	Oct 2020 – Jul 2021	p-value*
	N (%)/ Mean (SD)	N (%)/ Mean (SD)	N (%)/ Mean (SD)	
Total valid data collected	577	146	293	
School type				
Primary	267 (46%)	87 (60%)	137 (47%)	**0.013**
Secondary	310 (54%)	59 (40%)	156 (53%)	
Sex				
Female	333 (58%)	100 (68%)	227 (77%)	**<0.001**
Male	244 (42%)	46 (32%)	66 (23%)	
Age (years)	12.85 (2.61)	12.14 (2.90)	11.93 (2.11)	**<0.001**
Anthropometric parameters				
Height (z-score)	-0.39 (1.50)	-0.41 (1.49)	-0.29 (1.10)	0.535
Weight (z-score)	-0.10 (1.32)	-0.03 (1.38)	-0.02 (1.25)	0.672
BMI (z-score)	0.17 (1.25)	0.24 (1.26)	0.13 (1.29)	0.683
Body fat (%)	20.99 (9.63)	21.38 (9.27)	20.72 (8.67)	0.788
Body Status				
Underweight	12 (2%)	2 (1%)	12 (4%)	0.576
Normal	442 (77%)	111 (76%)	227 (77%)	
Overweight	85 (15%)	21 (14%)	38 (13%)	
Obese	34 (6%)	7 (5%)	15 (5%)	
Missing	4 (1%)	5 (3%)	1 (0%)	
Social Economic Status (SES)	-0.08 (1.53)	0.18 (1.69)	0.03 (1.52)	0.301

*Chi-square test was used for categorical variables and one-way ANOVA was used for continuous variables.

3.2. Changes in PA, Sleep time, and Screen time (Table 2)

After adjusting for age, sex, and SES index, the average step count and MVPA time per day decreased during school closures and after school reopening compared to pre-pandemic. Moreover, the average sedentary time per day increased when schools reopened after the pandemic.

Compared to their counterparts prior to the pandemic, students had longer sleep duration, lower sleep efficiency, and higher SFI during school closure, whereas students had longer sleep latency and lower sleep efficiency after school reopening.

Students' screen time for both academic and non-academic purposes increased during both school closures and after school reopening compared to pre-pandemic.

Comparing between SES, a lower SES was associated with higher SFI, lower MVPA time, and longer total screen time pre-pandemic and during school closures. Meanwhile, lower SES was associated with a longer sedentary time during school closure.

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Table 2. Changes in weekly PA, Sleep, Screen time.

	Pre-pandemic (reference)	During School Closure			School Partially Reopened		
Physical activity	Mean (SD)	Mean (SD)	β (SE)	p-value	Mean (SD)	β (SE)	p-value
Step count per day	10969.33 (2492.15)	8472.51 (3295.39)	-2692.83 (235.04)	**<0.001**	9547.04 (2455.05)	-1562.17 (189.24)	**<0.001**
Sedentary time per day (hr)	10.46 (1.45)	10.64 (1.83)	0.16 (0.16)	0.292	10.85 (1.69)	0.61 (0.12)	**<0.001**
MVPA time per day (hr)	0.47 (0.35)	0.42 (0.49)	-0.09 (0.03)	**0.007**	0.44 (0.33)	-0.08 (0.03)	**<0.001**
Sleep							
Latency (min)	43.66 (50.83)	55.61 (81.31)	7.56 (6.48)	0.243	56.83 (52.13)	11.96 (4.72)	**0.011**
Actual sleep duration (hr)	7.45 (1.03)	8.76 (1.28)	1.19 (0.11)	**<0.001**	7.55 (1.09)	-0.07 (0.09)	0.438
Sleep time (HH:MM)	23:29 (00:53)	00:30 (01:17)	62.43 (5.68)	**<0.001**	23:39 (00:51)	14.92 (4.52)	**0.001**
Wake time (HH:MM)	07:11 (00:39)	09:54 (01:31)	115.14 (6.26)	**<0.001**	07:25 (00:59)	12.53 (4.98)	**0.012**
Efficiency (%)	95.72 (4.18)	91.07 (8.7)	-4.27 (0.54)	**<0.001**	95.25 (4.21)	-0.86 (0.43)	**0.047**
SFI	27.62 (7.34)	35.3 (11.75)	7.91 (0.88)	**<0.001**	27.56 (7.345)	0.72 (0.7)	0.306
Screen time							
Level of parental guidance	1.68 (0.56)	1.65 (0.56)	-0.05 (0.06)	0.407	1.76 (0.54)	0.03 (0.04)	0.497
Non-academic screen time per day (hr)	4.38 (4.3)	4.54 (4.55)	1.16 (0.4)	**0.003**	5.60 (4.22)	1.87 (0.32)	**<0.001**
Academic screen time per day (hr)	1.01 (1.33)	1.69 (2.14)	0.6 (0.17)	**<0.001**	2.92 (2.24)	1.93 (0.14)	**<0.001**
Overall screen time per day (hr)	5.39 (5.10)	6.23 (5.80)	1.79 (0.48)	**<0.001**	8.52 (5.40)	3.85 (0.38)	**<0.001**

3.3. Changes in PA, Sleep time, and Screen time by School Grade

3.3.1. Primary schools (Grade 1 to Grade 6) (Table 3)

After adjusting for age, sex, and SES index, the average step count and MVPA time per day decreased during school closures compared with pre-pandemic. Moreover, students also had longer sleep latency, higher SFI, and increased academic screen time per day during school closure.

After school reopening, students had lesser step counts per day, shorter sleep duration, poorer sleep efficiency during school days, and an increase in both academic and non-academic screen time in both school days and holidays compared to pre-pandemic.

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Table 3. Changes in weekly PA, Sleep and Screen time among primary school students.

	Pre-pandemic (reference)	During School Closure			School Partially Reopened		
Physical activity	Mean (SD)	Mean (SD)	β (SE)	p-value	Mean (SD)	β (SE)	p-value
Step count per day	11902.36 (2100.06)	9594.29 (2445.65)	-1961.05 (312.71)	**<0.001**	10433.02 (2493.44)	-1165.94 (258.07)	**<0.001**
School days	11999.24 (2026.46)	-	-	-	10682.54 (2663.60)	-1127.8 (256.02)	**<0.001**
Holidays	11713.80 (3599.98)	9594.29 (2445.65)	-1960.99 (471.21)	**<0.001**	9836.68 (3248.60)	-1317.95 (411.12)	**0.001**
Sedentary time per day (hr)	10.12 (1.29)	10.07 (1.61)	-0.25 (0.19)	0.181	10.13 (1.46)	0.00 (0.15)	0.977
School days	10.23 (1.36)	-	-	-	10.33 (1.51)	0.21 (0.16)	0.202
Holidays	9.91 (1.80)	10.07 (1.61)	0.03 (0.24)	0.899	9.56 (2.08)	-0.59 (0.21)	**0.005**
MVPA time per day (hr)	0.64 (0.33)	0.50 (0.33)	-0.11 (0.05)	**0.018**	0.62 (0.35)	0.02 (0.04)	0.572
School days	0.63 (0.33)	-	-	-	0.61 (0.35)	0.01 (0.04)	0.881
Holidays	0.68 (0.51)	0.50 (0.33)	-0.17 (0.07)	**0.016**	0.65 (0.49)	0.05 (0.06)	0.473
Sleep							
Latency (min)	53.19 (40.88)	83.68 (64.82)	27.65 (6.78)	**<0.001**	60.31 (44.30)	5.77 (5.54)	0.298
School days	53.96 (44.17)	-	-	-	62.87 (42.91)	8.58 (5.52)	0.120
Holidays	50.41 (59.49)	83.68 (64.82)	31.29 (9.13)	**0.001**	52.69 (62.63)	-0.64 (8.08)	0.937
Actual sleep duration (hr)	7.95 (0.79)	8.80 (1.03)	0.85 (0.13)	**<0.001**	7.77 (0.90)	-0.17 (0.1)	0.089
School days	7.72 (0.79)	-	-	-	7.44 (0.83)	-0.27 (0.1)	**0.007**
Holidays	8.66 (1.47)	8.80 (1.03)	0.11 (0.21)	0.589	8.85 (1.37)	0.08 (0.18)	0.658
Sleep time (HH:MM)	23:07 (01:21)	00:15 (01:22)	64.3 (7.09)	**<0.001**	23:21 (00:45)	13.25 (5.79)	**0.022**
School days	22:57 (00:45)	-	-	-	23:11 (00:45)	13.41 (5.53)	**0.015**
Holidays	23:37 (00:54)	00:15 (01:22)	35.39 (9.16)	**<0.001**	23:52 (01:11)	10.77 (8.11)	0.184
Wake time (HH:MM)	07:16 (00:36)	09:22 (01:15)	119.96 (6.33)	**<0.001**	07:21 (00:39)	6.37 (5.17)	0.218
School days	06:49 (00:26)	-	-	-	06:51 (00:29)	2.95 (3.41)	0.388
Holidays	08:43 (01:37)	09:22 (01:15)	35.78 (13.60)	0.009	09:00 (01:26)	14.83 (12.04)	0.218
Efficiency (%)	95.81 (3.53)	94.13 (4.45)	-1.15 (0.50)	0.023	95.92 (3.35)	-0.19 (0.41)	0.639
School days	97.13 (2.94)	-	-	-	96.43 (3.66)	-0.80 (0.40)	**0.044**
Holidays	91.61 (8.82)	94.13 (4.45)	2.47 (1.08)	**0.022**	94.28 (4.85)	1.93 (0.95)	**0.043**
SFI	26.89 (6.57)	31.11 (7.87)	4.01 (1.00)	**<0.001**	27.23 (6.70)	0.41 (0.82)	0.614
School days	25.44 (6.73)	-	-	-	26.85 (6.97)	1.24 (0.87)	0.153
Holidays	31.87 (12.06)	31.11 (7.87)	-0.24 (1.54)	0.874	28.97 (8.95)	-2.68 (1.37)	0.050
Screen time							
Level of parental guidance	1.87 (0.51)	1.94 (0.49)	0.04 (0.08)	0.586	1.86 (0.52)	0.02 (0.06)	0.765
Non-academic screen time per day (hr)	1.81 (2.69)	2.65 (3.60)	0.56 (0.45)	0.211	4.5 (3.78)	2.67 (0.37)	**<0.001**
School days	1.39 (2.42)	-	-	-	3.87 (3.76)	2.27 (0.34)	**<0.001**
Holidays	2.86 (4.09)	2.65 (3.60)	0.95 (0.66)	0.153	6.09 (5.27)	3.62 (0.54)	**<0.001**
Academic screen time per day (hr)	0.38 (0.92)	0.88 (1.28)	0.55 (0.21)	**0.010**	2.98 (2.38)	2.44 (0.18)	**<0.001**
School days	0.43 (0.91)	-	-	-	3.49 (3.01)	3.02 (0.22)	**<0.001**
Holidays	0.54 (1.21)	0.88 (1.28)	0.7 (0.21)	**0.001**	1.71 (1.87)	0.95 (0.18)	**<0.001**
Overall screen time per day (hr)	2.28 (3.31)	3.53 (1.65)	1.12 (0.58)	0.055	7.48 (5.32)	5.11 (0.48)	**<0.001**
School days	1.83 (3.02)	-	-	-	7.36 (6.02)	5.28 (0.49)	**<0.001**
Holidays	3.4 (4.65)	3.53 (1.65)	1.65 (0.74)	**0.027**	7.79 (5.75)	4.56 (0.61)	**<0.001**

Latency - Difference between monitor recorded and self-reported sleep time (min); MVPA – Moderate to vigorous PA; SFI - Sleep fragmentation Index

3.3.1. Secondary schools (Grade 7 to Grade 12) (Table 4)

During school closure, students had decreased step counts per day, less MVPA time per day, more sedentary time, poorer sleep efficiency, and a higher SFI compared with pre-pandemic. Moreover, both academic and non-academic screen time increased during school closure.

After school reopening, students had lesser step counts and lesser MVPA time per day but increased sedentary time per day compared with pre-pandemic. In addition, students had longer sleep latency, shorter sleep duration, lower SFI, and increased academic and non-academic screen time after school reopening.

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Table 4. Changes in weekly PA, Sleep and Screen time among secondary school students.

	Pre-pandemic (reference)	During School Closure			School Partially Reopened		
Physical activity	Mean (SD)	Mean (SD)	β (SE)	p-value	Mean (SD)	β (SE)	p-value
Step count per day	9692.94 (2492.86)	6111.86 (2196.68)	-4035.39 (381.47)	**<0.001**	8795.19 (2157.77)	-1519.01 (348.77)	**<0.001**
School days	9997.45 (2422.58)	-	-	-	9454.58 (2218.24)	-1333.44 (360.77)	**<0.001**
Holidays	8786.08 (4481.52)	6111.86 (2196.68)	-2955.5 (612.03)	**<0.001**	7550.07 (2575.63)	-1514.08 (641.59)	**0.018**
Sedentary time per day (hr)	10.79 (1.48)	11.61 (1.51)	0.79 (0.27)	**0.003**	11.48 (1.63)	0.83 (0.23)	**<0.001**
School days	10.93 (1.64)	-	-	-	11.93 (1.80)	1.07 (0.27)	**<0.001**
Holidays	10.62 (1.82)	11.61 (1.51)	1.11 (0.31)	**<0.001**	10.92 (1.68)	0.41 (0.32)	0.194
MVPA time per day (hr)	0.32 (0.27)	0.17 (0.18)	-0.15 (0.04)	**0.001**	0.28 (0.22)	-0.07 (0.04)	0.061
School days	0.31 (0.26)	-	-	-	0.27 (0.20)	-0.09 (0.04)	**0.020**
Holidays	0.41 (0.54)	0.17 (0.18)	-0.24 (0.07)	**0.001**	0.28 (0.24)	-0.09 (0.07)	0.220
Sleep							
Latency (min)	33.16 (58.25)	5.08 (84.24)	-22.8 (12.02)	0.058	53.97 (57.78)	23.03 (10.02)	**0.022**
School days	37.32 (59.97)	-	-	-	65.50 (61.85)	31.19 (9.86)	**0.002**
Holidays	10.86 (70.18)	5.08 (84.24)	0.02 (15.86)	0.999	26.71 (68.40)	10.68 (15.66)	0.495
Actual sleep duration (hr)	6.94 (0.95)	8.72 (1.64)	1.79 (0.22)	**<0.001**	7.31 (1.20)	-0.01 (0.19)	0.976
School days	6.58 (0.92)	-	-	-	6.41 (0.99)	-0.35 (0.16)	**0.030**
Holidays	8.65 (1.65)	8.72 (1.64)	0.23 (0.31)	0.466	8.87 (1.41)	0.39 (0.32)	0.235
Sleep time (HH:MM)	23:57 (00:52)	00:54 (01:03)	51.12 (9.47)	**<0.001**	23:56 (00:50)	8.57 (8.63)	0.321
School days	23:52 (00:53)	-	-	-	23:53 (00:54)	12.73 (8.75)	0.146
Holidays	00:29 (01:05)	00:54 (01:03)	16.82 (12.59)	0.182	00:05 (01:05)	-21.18 (13.41)	0.114
Wake time (HH:MM)	07:05 (00:42)	10:45 (01:30)	207.70 (11.73)	**<0.001**	07:29 (01:12)	11.63 (10.53)	0.269
School days	06:38 (00:27)	-	-	-	06:26 (00:32)	-9.84 (4.71)	**0.037**
Holidays	09:35 (01:33)	10:45 (1:30)	64.15 (18.75)	**0.001**	09:22 (01:35)	-0.86 (19.64)	0.965
Efficiency (%)	95.56 (4.31)	85.48 (11.69)	-9.36 (1.08)	**<0.001**	94.58 (4.79)	-1.16 (0.98)	0.236
School days	96.03 (4.42)	-	-	-	95.73 (4.78)	-0.34 (0.81)	0.674
Holidays	91.95 (8.08)	85.48 (11.69)	-6.17 (1.67)	**<0.001**	92.27 (6.94)	-1.2 (1.75)	0.491
SFI	28.28 (7.69)	43.12 (13.89)	14.5 (1.62)	**<0.001**	27.82 (7.96)	0.03 (1.48)	0.986
School days	27.53 (8.06)	-	-	-	25.74 (9.17)	1.07 (0.27)	**<0.001**
Holidays	33.46 (11.11)	43.12 (13.89)	9.38 (2.14)	**<0.001**	31.14 (9.00)	-0.54 (2.30)	0.813
Screen time							
Level of parental guidance	1.45 (0.53)	1.26 (0.40)	-0.16 (0.09)	0.067	1.68 (0.54)	0.04 (0.08)	0.572
Non-academic screen time per day (hr)	6.6 (4.19)	7.64 (4.27)	0.61 (0.77)	0.422	6.44 (4.36)	0.69 (0.64)	0.278
School days	5.8 (4.43)	-	-	-	5.62 (4.19)	0.39 (0.68)	0.559
Holidays	8.62 (5.99)	7.64 (4.27)	1.36 (1.04)	0.192	8.48 (5.6)	1.46 (0.85)	0.087
Academic screen time per day (hr)	1.49 (1.45)	2.99 (2.59)	1.29 (0.34)	**<0.001**	2.87 (2.13)	1.36 (0.28)	**<0.001**
School days	1.49 (1.49)	-	-	-	3.01 (2.28)	1.53 (0.3)	**<0.001**
Holidays	1.49 (1.73)	2.99 (2.59)	1.27 (0.38)	**0.001**	2.53 (2.28)	1.08 (0.32)	**0.001**
Overall screen time per day (hr)	8.09 (4.84)	10.64 (5.25)	1.91 (0.92)	**0.039**	9.31 (5.34)	2.12 (0.75)	**0.005**
School days	7.29 (5.11)	-	-	-	8.63 (5.3)	1.97 (0.81)	**0.015**
Holidays	10.11 (6.55)	10.64 (5.25)	2.65 (1.17)	**0.023**	11.01 (6.38)	2.86 (0.95)	**0.003**

Latency - Difference between monitor recorded and self-reported sleep time (min)

3.4. Influence of the reallocation of time use on sleep quality

Table 5 shows the results of the compositional data analysis of 15-minute time reallocation effects on sleep quality during the three periods. There was no significant influence on sleep quality for any reallocation of time pre-pandemic and after school reopening. On the contrary, reallocation of MVPA time significantly affected sleep quality during school closures. As MVPA time increased, sleep fragmentation index decreased and vice versa.

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Table 5. Compositional data analysis of 15 min time relocation effects to sleep quality during different period.

		Predicted difference (95% confidence interval)							
Add 15 min	Remove 15 min	Overall		Pre-pandemic		During school closure		After school partially reopened	
Screen time	MVPA	0.865	(0.563, 1.168)	0.332	(-0.177, 0.84)	**2.013**	**(0.481, 3.546)**	0.546	(-0.114, 1.206)
Screen time	Sleep	-0.025	(-0.063, 0.012)	-0.016	(-0.178, 0.145)	0.074	(-0.063, 0.212)	-0.018	(-0.046, 0.009)
Screen time	Other activities	0.013	(-0.02, 0.045)	0.001	(-0.152, 0.153)	0.099	(-0.024, 0.223)	0.011	(-0.016, 0.039)
MVPA	Screen time	-0.616	(-0.831, -0.401)	-0.229	(-0.834, 0.376)	**-1.293**	**(-2.212, -0.374)**	-0.343	(-0.759, 0.072)
MVPA	Sleep	-0.638	(-0.864, -0.413)	-0.242	(-0.608, 0.124)	**-1.171**	**(-2.118, -0.224)**	-0.362	(-0.798, 0.074)
MVPA	Other activities	-0.600	(-0.816, -0.384)	-0.225	(-0.569, 0.119)	**-1.146**	**(-2.092, -0.200)**	-0.332	(-0.749, 0.085)
Sleep	Screen time	0.022	(-0.031, 0.075)	0.012	(-0.425, 0.45)	-0.123	(-0.316, 0.070)	0.018	(-0.009, 0.046)
Sleep	MVPA	0.890	(0.575, 1.205)	0.348	(-0.179, 0.874)	**1.939**	**(0.372, 3.506)**	0.564	(-0.116, 1.244)
Sleep	Other activities	0.038	(0.024, 0.051)	0.017	(-0.008, 0.042)	0.024	(-0.032, 0.081)	0.029	(-0.008, 0.067)
Other activities	Screen time	-0.015	(-0.063, 0.032)	-0.004	(-0.449, 0.441)	-0.148	(-0.324, 0.029)	-0.010	(-0.034, 0.015)
Other activities	MVPA	0.853	(0.548, 1.158)	0.331	(-0.174, 0.836)	**1.914**	**(0.350, 3.477)**	0.536	(-0.126, 1.197)
Other activities	Sleep	-0.038	(-0.051, -0.024)	-0.017	(-0.042, 0.008)	-0.025	(-0.078, 0.027)	-0.028	(-0.063, 0.006)

4. Discussion

To the best of our knowledge, this is one of the first studies using objective PA monitoring data to demonstrate changes in sleep patterns and PA level among school-aged children during different phases of the COVID-19 pandemic. Previous studies conducted in other countries relied on self-reported questionnaires and compared their findings with pre-COVID data from other studies, which introduces potential bias [32-34]. Our study provides more robust data by using a repeated cross-sectional design to compare pre-pandemic, school closure, and school reopening periods. We objectively demonstrated that children had lower PA levels, longer sleep duration, and longer screen time during school closures (Mar 2020 – Apr 2020) compared with pre-pandemic (Sep 2019 – Jan 2020). We also found some of these parameters improved after school reopening (Oct 2020 and Jul 2021), although the impacts of physical inactivity, prolonged screen time, and sleep disturbances appeared to persist. This study found that the COVID-19 pandemic is having potentially significant long-term impacts on the lifestyle and physical activity of school-aged children, which adds an important piece of evidence to the current literature.

In Hong Kong, only around 8% of school-aged children fulfill the recommended PA levels set by the World Health Organization in 2013 [35]. Our study found that physical inactivity has become even more prevalent after the COVID-19 outbreak. Given the strong link between childhood physical inactivity and long-term major diseases such as cardiovascular problems 3, child care providers and parents should pay attention to the potential lifestyle changes in children during the pandemic [36;37] and school teachers should promote students' out-of-school PA by guiding students, helping them to set realistic goals and encouraging them self-monitoring [38]. In a recent study conducted by Tso et al., children and their families had more psychosocial problems during the COVID-19 pandemic, and these problems were more significant in vulnerable families such as in children with chronic illnesses and those with special educational needs. In particular, the quality of life of these children was found to be negatively correlated with physical inactivity and prolonged screen time [39]. Findings from our study imply the worsening physical inactivity during prolonged school closures persisted after reopening of schools, which may pose further health risks to children in the long term beyond the pandemic.

There were significant changes in sleep patterns during the different study periods. Although sleep duration was longer during school closures than pre-pandemic, this was still within the recommendations of the American Academy of Sleep Medicine [40]. However, the overall sleep quality was poorer as evidenced by delayed bedtime and wake-up time, increased in-bed duration, longer sleep latency, and increased movement and SFI. During school closures, some primary school students reported sleeping after 2 a.m., which was not observed in the pre-pandemic group. These children will likely have disturbed circadian rhythm. The circadian rhythm is an endogenous rhythm that assists humans in keeping their biological clock on a 24-hour cycle. [41]. In children and adolescents, circadian rhythm disorders and sleep problems are known to be associated with physical, cognitive, and behavioral problems, such as obesity, hyperactivity-impulsivity,

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inattention, daytime sleepiness, emotion and poorer cognitive performance [42-45]. During the school closures period, all students attended online courses from home instead of going to school. Without proper parental supervision, the increase in screen time could cause later sleep and wake-up times, resulting in an overall longer sleep duration. Moreover, although most of the sleep patterns recovered after school partially reopened, slight delay in bed time was still found. . Delayed sleep phase may result in lower learning capacity and academic performance. Therefore, parents and school authorities should give more guidance on sleep habits of children [46].

Excessive screen time was also reported in primary school students. The switch to online teaching meant longer use of electronic devices for academic purposes, but recreational screen time also increased [47]. Excessive screen time in school-aged children has been associated with increased risk of myopia, obesity, cardio-metabolic problems, and behavioral issues [48-50]. The American Academy of Pediatrics recommends that families and pediatricians should collaborate to develop a Family Media Use Plan to guide their children on media use [51].

The findings of this study need to be interpreted with the following caveats. First, the sample size was relatively small due to the design of objective PA monitoring during the COVID-19 outbreak. Second, the study subjects were recruited on a voluntary basis, which means selection bias may be a concern. However, the availability of repeated measurements for the lifestyle behaviors allowed us to assess the associations between the behaviors alone and in combination with the three time periods (pre-pandemic, school closure, and school reopening) over nearly 18 months after the start of the pandemic. Our study was able to dynamically capture previously unreported differences in children's PA levels and sleep patterns by using an objective PA monitoring approach.

5. Conclusions

This study found that there were adverse and persistent changes in sleep patterns, screen time, and physical activity levels during the period of school closures. Professionals should provide parents and children with appropriate advice on maintaining physical activity, good sleep hygiene, and appropriate use of electronic devices during this challenging period, particularly during school closures. As Hong Kong is now in the fifth wave of COVID-19 since early January 2022, the Hong Kong Government has again tightened social distancing measures, which may further increase the long-term risks for children. Further study is needed to longitudinally follow up these children and their families.

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