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ORIGINAL ARTICLE

Cardiopulmonary Exercise Performance in the Pediatric and Young Adult Population Before and During the COVID-19 Pandemic

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Abstract
Physical activity (PA) decreased and sedentary behavior (SB) increased in the pediatric population during the Coronavirus Disease 2019 (COVID-19) pandemic. We examined the effects of PA and SB on cardiopulmonary exercise performance in children, adolescents and young adults both with and without underling cardiac disease, and hypothesized that there will be a change in aerobic and physical working capacity during the pandemic. This was a single-center retrospective longitudinal cohort study in patients age 6–22 years who underwent serial maximal cardiopulmonary exercise stress testing before and during the COVID-19 pandemic. Metabolic variables were obtained; PA and SB data were extracted from clinic notes. A total of 122 patients (60% male) underwent serial exercise testing with a median age of 14 years at the first CPET. Predicted peak aerobic capacity significantly decreased among both females and males during the pandemic, even after adjusting for changes in somatic growth. There was no significant change in physical working capacity during the pandemic. Patients who were more aerobically fit experienced a greater decrease in aerobic capacity during the pandemic compared to those less fit. In conclusion, cardiopulmonary exercise performance, notably aerobic activity, decreased during the COVID-19 pandemic in children, adolescents and young adults compared to pre-pandemic values. This decline was most notable in those with the highest pre-pandemic aerobic capacity values and was independent of somatic growth or changes in BMI. This study has public health implications and demonstrates the importance of PA on overall cardiovascular health.

Keywords Pediatrics · COVID-19 · Cardiopulmonary exercise test · Physical activity

Background

The World Health Organization (WHO) announced that the Coronavirus Disease 2019 (COVID-19) was a global pandemic in March 2020. Shortly thereafter, social distancing practices were enacted, and lockdowns were put into effect [1]. Beginning mid-March 2020 in the United States, one of the measures taken in all 50 states was closure of primary and secondary schools, with most of these closures extending through the end of the 2019–2020 school year [2]. Additionally, many schools reopened for the 2020–2021 school year as entirely virtual or with a hybrid approach [3]. Most sports teams cancelled practices and competitions, exercise classes and gyms shut down, and in many areas, public parks were closed to the public. While these were necessary for mitigating the spread of COVID-19, the effects on physical activity (PA) and sedentary behavior (SB) in children could be profound.

PA is any bodily movement using skeletal muscle that results in expending energy [4]. This may include walking, swimming, running, biking, free play, and even household chores. SB is defined as a behavior while awake that has an energy expenditure of ≤ 1.5 metabolic equivalents (METs) while sitting or reclining [5]. This may include watching television, playing video games, and using the computer. PA is important not just for cardiovascular health but also for mental health and physical well-being. This is true for both healthy children as well as for those with congenital heart disease [6]. Given that COVID-19 is a new and ongoing pandemic, there are limited data on PA and SB during this time in children and adolescents. Recent studies of self-reported survey data and device-based measures have

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shown a decrease in PA and an increase in SB during the COVID-19 pandemic in children [7, 8]. To our knowledge, no studies have looked at the effect of these changes on cardiopulmonary exercise performance. Additionally, there are no studies to date evaluating the impact that the pandemic has had on exercise performance in the pediatric population. We hypothesize that there will be a decrease in exercise performance in children, adolescents and young adults during the COVID-19 pandemic compared to pre-pandemic values.

Materials and Methods

This was a single-center retrospective longitudinal cohort study in children, adolescents and young adults who underwent serial maximal cardiopulmonary exercise stress testing (CPET) before and then during the COVID-19 pandemic as part of routine standard of care. Clinical data were abstracted from the medical chart. Written informed consent was waived by the Institutional Review Board of the Children's Hospital of Philadelphia due to the retrospective nature of the study.

Study Cohort

The study cohort consisted of all patients aged 6 to 22 years at the most recent maximal CPET performed at the Children's Hospital of Philadelphia. Inclusion criteria included performance of at least one maximal CPET before the COVID-19 pandemic (January 1, 2019 to March 13, 2020) and at least 1 CPET during the COVID-19 pandemic (June 1, 2020 to May 7, 2021). In patients with underlying congenital or acquired heart disease or in those with cardiac symptoms, serial CPET is commonly performed at our institution as standard of care. Patients were excluded from this study if they met the following criteria: history of heart transplantation, maximal CPET criteria was not met, new cardiac medication was started or dose escalation of previous cardiac medication occurred after the first CPET, cardiac intervention such as cardiac catheterization or cardiac surgery was performed after the first CPET, or a change in systolic ventricular function by echocardiogram occurred after the first CPET.

Exercise Protocol

Subjects were included if at least two maximal CPET using an electronically braked cycle ergometer (SensorMedics VIAsprint 150P, Yorba Linda, California, USA) were performed during the study period. A maximal test was defined as achieving a maximal respiratory exchange ratio (RER) greater than or equal to 1.10. The protocol consisted of three minutes of pedaling in an unloaded state (zero watts), followed by a ramp increase in work rate to maximal exercise capacity and peak work rate [10]. The steepness of the ramp protocol was designed to achieve a peak work rate of 3 watts/kg in females and preadolescent males and 3.5 watts/kg in adolescent males in 10 to 12 min of cycling time, with the ramp speed increase ranging from 10 to 20 watts per minute based on subject weight. Subjects were encouraged to maintain a pedaling cadence (revolutions per minute) between 60 and 90 revolutions per minute throughout the study with average 60 to 70 revolutions per minute maintained until the last minute of exercise where subjects were encouraged to increase their peddling speed to achieve maximal work rate. This range was within the specified parameters of the cycle ergometer to maintain an accurate work rate. The patients were able to view their cadence on a meter located in the center of the bicycle handlebars. A clinical exercise physiologist and staff pediatric cardiologist trained to provide age-appropriate encouragement to achieve maximal exercise performance were present during the exercise stress testing.

Breath-by-breath metabolic data were obtained during exercise and the first 2 min of recovery using a commercially available metabolic cart (SensorMedics V29 Encore, Yorba Linda, California, USA). Measured variables included: minute oxygen consumption (VO_2) at maximal exercise and at ventilatory anaerobic threshold (VAT), physical working capacity at maximal exercise (work rate in watts), heart rate (HR) at rest and maximal exercise, and RER at maximal exercise. VAT was measured manually by both the exercise physiologist and the supervising cardiologist using the V-slope and ventilatory equivalents methods. All data were averaged over 10 s intervals for measurements at VAT and maximal exercise. Values for predicted peak VO_2 and predicted peak work rate were reported using recently published pediatric normative exercise data that incorporates age, gender, race, and BMI adjusted predicted values to account for interval changes in somatic growth during serial CPET [9]. We define normal values as > 80% of peak predicted.

Statistical Analysis

The primary study aim was to determine the changes in measurements of maximal and submaximal cardiopulmonary exercise performance during the COVID-19 pandemic compared to pre-pandemic values. Secondary outcome measurements included change in physical working capacity and BMI percentile compared to during and before the COVID-19 pandemic. PA levels and SB (school structure used as a surrogate) were also examined. Patient demographics and clinical data are presented using standard measurements of central tendency and variability presented as either a number with percentage or as median value with interquartile range (IQR). Pre- and during COVID-19 pandemic clinical and CPET data were compared using the two-sampled t test for proportions or the Wilcoxon matched-pairs signed rank test based non-parametric data distribution. Linear regression analysis was used to evaluate factors associated with change in peak predicted VO_2 during the pandemic. All p values were two-sided with $p<0.05$ considered statistically significant. Analyses were performed using STATA v15.1.

Results

A total of 122 patients (60% male) underwent serial CPET before and during the COVID-19 pandemic. The majority (84%) were white. The median age at the first CPET was 14 years (IQR 12–16). The underlying cardiac diagnosis or reason for referral is shown in Table 1. Before the pandemic, most patients (81%) received in-person school instruction. In contrast, during the COVID-19 pandemic, a plurality of patients had either a hybrid (12%) or remote (36%) school learning compared to in-person learning (9%) at the time of follow-up CPET. However, no data were available on the school status of 46% of the patients during the pandemic. Nearly half (43%) of patients reported a decrease in PA during the COVID-19 pandemic.

Pre-pandemic and during pandemic CPET data are shown in Table 2. There was an increase in BMI during the pandemic compared to before among both males ($p<0.001$) and females ($p=0.003$). Aerobic capacity significantly decreased among both females (92% vs. 82% predicted peak VO_2, $p=0.047$) and males (96% vs. 92% predicted peak VO_2, $p=0.008$) during the pandemic, even after accounting for changes in somatic growth. However, there was no significant change in physical working capacity (predicted peak work) during the pandemic.

Patients who were more physically fit based on a pre-pandemic peak predicted VO_2 had a greater decrease in aerobic capacity during the pandemic compared to those who were less fit before the pandemic ($p=0.022$; Fig. 1). Additionally, those who reported a decrease in PA during the pandemic also had a significantly greater decrease in peak predicted VO_2 during the pandemic compared to those who reported a similar PA level during the pandemic (− 11.7% vs. − 1.7%; $p=0.013$). School structure (in-person, hybrid, remote) during the pandemic was not associated with exercise performance changes ($p=0.298$), although absent available data regarding school structure in some clinic notes may have limited the reliability of this finding.

Table 1 Patient demographics

	Total $N=122$
Age at EST #1	14 (IQR 12–16)
Age at EST #2	16 (IQR 13–17)
Male	73 (59.8%)
Race	
White	102 (83.6%)
Black or African American	12 (9.8%)
Asian	2 (1.6%)
American Indian or Alaska Native	1 (0.8%)
Other	5 (4.1%)
Diagnosis	
DCM	3 (2.5%)
HCM	11 (9.0%)
LQTS	36 (29.5%)
AAOCA	13 (10.7%)
Fontan	5 (4.1%)
Other CHD	11 (9.0%)
CPVT	2 (1.6%)
Family history/screening	10 (8.2%)
Chest pain/syncope	4 (3.3%)
Other arrhythmia	15 (12.3%)
Other	12 (9.8%)
School structure before COVID pandemic	
In-Person	99 (81.1%)
Hybrid	1 (0.8%)
Remote	2 (1.6%)
Undocumented/unclear	20 (16.4%)
School structure during COVID pandemic	
In-person	11 (9.0%)
Hybrid	15 (12.3%)
Remote	44 (36.1%)
Undocumented/unclear	52 (42.6%)
Physical activity during pandemic	
Same	23 (33.8%)
Decreased	29 (42.6%)
Increased	2 (2.9%)
Undocumented/unclear	14 (20.6%)

IQR interquartile range

Discussion

Our study examined the effects of PA and SB on cardiopulmonary exercise performance in the young during the COVID-19 pandemic. We found cardiopulmonary exercise performance, specifically percent predicted peak aerobic activity, decreased during the COVID-19 pandemic in children, adolescents and young adults compared to pre-pandemic values. These changes occurred independent of changes in somatic growth and BMI. School structure as a surrogate for SB was not associated with changes in exercise performance, although the accuracy of this finding may be explained by missing data regarding school structure in clinic notes reviewed. Similar to previous reports, we also found an increase in BMI over the study period [10].

Table 2 Serial exercise stress test data

	EST #1 Before COVID pandemic	EST #2 During COVID pandemic	*P* value (Mann–Whitney)
Males (*N* = 73)			
Metabolics performed	41 (58%)	44 (60%)	0.758
Weight (Kg)	58 (46–74)	64 (53–76)	**< 0.001**
Height (cm)	171 (155–177)	172 (164–178)	**< 0.001**
BMI	22 (18–24)	22 (20–24)	**< 0.001**
Peak VO_2 (mL/kg/min)	41 (37–48)	40 (34–48)	**0.008**
Peak VO_2 (L/min)	3 (2–3)	3 (2–3)	0.726
Predicted peak VO_2 (%)	96 (88–107)	92 (83–106)	**0.008**
VO_2 at anaerobic threshold (mL/kg/min)	24 (21–28)	22 (18–27)	**0.018**
VO_2 at anaerobic threshold (L/min)	1.4 (1.1–1.8)	1.4 (1.2–1.7)	0.914
Predicted VO_2 at anaerobic threshold (%)	97 (86–107)	91 (75–106)	0.084
Peak work (Watts)	160 (128–220)	182 (145–229)	**< 0.001**
Predicted peak work (%)	88 (71–99)	87 (72–101)	0.835
HR rest	66 (57–76)	65 (56–72)	0.133
HR peak	187 (160–193)	187 (161–194)	0.229
Females (*N* = 49)			
Metabolics performed	26 (55%)	22 (46%)	0.355
Weight (Kg)	58 (48–67)	61 (50–68)	**< 0.001**
Height (cm)	163 (157–167)	163 (157–169)	**< 0.001**
BMI	22 (19–24)	23 (20–25)	**0.003**
Peak VO_2 (mL/kg/min)	32 (28–37)	30 (25–34)	**0.044**
Peak VO_2 (L/min)	2 (2–2)	2 (1–2)	0.617
Predicted peak VO_2 (%)	92 (83–106)	82 (74–97)	**0.047**
VO_2 at anaerobic threshold (mL/kg/min)	19 (16–24)	18 (14–21)	0.362
VO_2 at anaerobic threshold (L/min)	1.1 (0.9–1.3)	1.1 (0.8–1.3)	0.927
Predicted VO_2 at Anaerobic Threshold (%)	96 (82–107)	88 (70–104)	0.248
Peak work (Watts)	130 (106–158)	130 (109–158)	0.704
Predicted peak work (%)	86 (68–100)	82 (68–100)	0.096
HR rest	68 (62–79)	70 (62–83)	0.081
HR peak	171 (162–187)	176 (155–190)	0.075

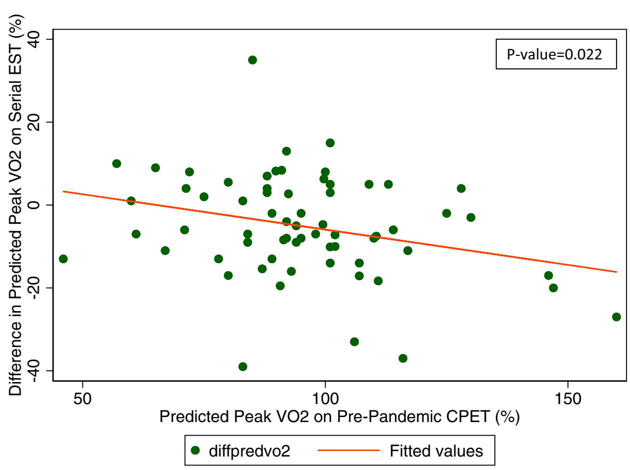

Fig. 1 Change in peak VO_2 during the pandemic based on pre-pandemic peak VO_2

There have been several studies looking at changes in PA using surveys during the COVID-19 pandemic in healthy youth [7, 8, 11]. All studies showed a decrease in PA during the pandemic. During the early days of the pandemic (March–April 2020), a Canadian study of children with congenital heart disease evaluated PA and found that step counts were significantly lower during this time compared to pre-pandemic step counts. A cross-sectional survey of 1000 children and adolescents evaluated self-reported PA, screen time, and mental health during October–November 2020 in the COVID-19 pandemic [11]. The study found that in the younger 6–10-year age group, 23.3% ($n = 119$) children performed 60 min/day of activity while an even smaller amount of children and adolescents in the older 11–17 year old age group achieved this ($n = 76$, 13.5%). Non-academic screen time was 4.0 and

5.1 h/day for the younger and older age group, respectively. In this study, children with more PA and less screen time had better mental health scores as well.

Recent studies in adults who were more active pre-pandemic had greater decreases in PA during the pandemic [12, 13]. Coincident with the decrease in PA, an increase in SB was observed. Additional studies measured changes in SB in children and adolescents using questionnaires and all showed increases in SB [14–16].

In our study, although most subjects had normal predicted values for peak oxygen consumption, we found subjects who self-reported a decrease in PA during the pandemic had a greater decrease in peak predicted VO_2 compared to subjects who did not have a change in self-reported PA levels. Furthermore, the greatest decrease in exercise performance was among those who were the most aerobically fit pre-pandemic. One explanation could be that these subjects were likely participating in competitive, structured sports, with practices and/or games multiple times per week pre-pandemic. For much of the study period, sports practices were cancelled leaving these subjects without their usual form of PA available, resulting in a more significant decrease in PA from baseline compared to those less aerobically fit. Another explanation is that detraining results in a rapid decrease in maximal VO_2 during the first month of detraining, and an approximate 16% decline over 12 weeks of physical deconditioning [17]. While the subjects with greater fitness pre-pandemic may still have a higher VO_2 during the pandemic, they likely had a greater percentage decrease compared to the less fit patient.

Although aerobic fitness decreased in correlation with decreased PA, this same effect was not observed with physical working capacity, even when considering change in somatic growth over time. This held true for both the more aerobically fit and less aerobically fit subjects. This finding may be explained by a small overall sample size, especially as the female subjects trended toward significantly lower working capacity as shown in Table 2. In addition, there may not have been a long enough interval between the first and second test in to show power or muscle strength loss [18].

In addition to decreased sports participation, another potential factor that may have impacted exercise performance during the COVID pandemic was change in mental health. PA and mental health are inextricably linked, and it is known that rates of depression and anxiety have increased during the pandemic [11]. These findings highlight the importance of developing mobile health strategies which encourage and allow for PA in children during the pandemic and at other times when PA may be limited. This study demonstrates the unintentional consequences of a necessary public health measure but should be kept in mind as further policy is developed and implemented.

Limitations

There were several potential limitations in the present study. This was a single-center study with a relatively small sample size, although the sample size is robust for this patient population. As this was a retrospective longitudinal chart review study, some patient data may have been unavailable, notably regarding school structure. Another limitation is the variation in clinical practice regarding the use of metabolic testing during the CPET that is an inherent limitation due to the retrospective observational nature of this study design. However, most subjects who had metabolic testing performed received metabolic testing on both CPET and thus can use the longitudinal data from serial testing to perform the statistical analyses on the metabolic data. Due to the small sample size, if the study was limited to only those who had metabolic testing, we would have had inadequate power to detect statistical differences. In addition, recall bias may have been introduced when the subjects described their amount of PA both pre- and during the pandemic. Another possible bias is the type of subjects evaluated, as one-third had congenital heart disease or cardiomyopathy. Therefore, the results may not be generalizable to the general population.

Conclusions and Future Directions

In conclusion, cardiopulmonary exercise performance, notably aerobic activity, decreased during the COVID-19 pandemic in children, adolescents and young adults compared to pre-pandemic values. This decline was most notable in those with the highest pre-pandemic aerobic capacity values and was independent of somatic growth or changes in BMI. PA decreases helped explain the changes in aerobic capacity. Future studies should examine if exercise performance returns to pre-pandemic values once schools and activities have returned to pre-pandemic levels. This study has public health implications for our youth and demonstrates the importance of PA on overall cardiovascular health.

Declarations

Conflict of interest The authors have no relevant conflicts of interest to report.

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