COVID-19 Leads to Accelerated Increases in Children's BMI z-Score Gain: An Interrupted Time-Series Study

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Introduction: The COVID-19 pandemic may have negatively impacted children's weight status owing to the closure of schools, increased food insecurity and reliance on ultraprocessed foods, and reduced opportunities for outdoor activity.

Methods: In this interrupted time-series study, height and weight were collected from children (*n*=1,770 children, mean age=8.7 years, 55.3% male, 64.6% Black) and were transformed into BMI z-score in each August/September from 2017 to 2020. Mixed-effects linear regression estimated yearly BMI z-score change before the COVID-19 pandemic year (i.e., 2017−2019) and during the COVID-19 pandemic year (i.e., 2019−2020). Subgroup analyses by sex, race (i.e., Black, White, other race), weight status (overweight or obese and normal weight), and grade (i.e., lower=kindergarten−2nd grade and upper=3rd−6th grade) were conducted.

Results: Before the COVID-19 pandemic, children's yearly BMI z-score change was +0.03 (95% CI= −0.10, 0.15). Change during the COVID-19 pandemic was +0.34 (95% CI=0.21, 0.47), an acceleration in BMI z-score change of +0.31 (95% CI=0.19, 0.44). For girls and boys, BMI z-score change accelerated by +0.33 (95% CI=0.16, 0.50) and +0.29 (95% CI=0.12, 0.46), respectively, during the pandemic year. Acceleration in BMI z-score change during the pandemic year was observed for children who were Black (+0.41, 95% CI=0.21, 0.61) and White (+0.22, 95% CI=0.06, 0.39). For children classified as normal weight, BMI z-score change accelerated by +0.58 (95% CI=0.40, 0.76). Yearly BMI z-score change accelerated for lower elementary/primary (+0.23, 95% CI=0.08, 0.37) and upper elementary/primary (+0.42, 95% CI=0.42, 0.63) children.

Conclusions: If similar BMI z-score accelerations occurred for children across the world, public health interventions to address this rapid unhealthy BMI gain will be urgently needed.
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INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic has spread to nearly every country around the world, and as of January 2021, there have been >90,000,000 reported cases and 2,000,000 total deaths worldwide.[1] The COVID-19 pandemic has introduced a variety of significant disruptions to individuals' lifestyles that could negatively impact children's health behaviors and weight status, including but not

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limited to the following. First, stay-at-home orders may have reduced children's opportunity for outdoor play and increased screen time. Studies have shown that children are less physically active when they are indoors,[2] and increased screen time is a risk factor for obesity.[3,4] Second, food insecurity may have increased dramatically during the COVID-19 pandemic,[5] with some estimates indicating that food insecurity has risen as much as 35%,[6,7] and food insecurity has been linked to increased risk for obesity.[8] Third, studies have also indicated that families may have increased their reliance on shelf-stable ultraprocessed foods during the COVID-19 pandemic.[9,10] Increased consumption of processed foods has been linked to obesity risk in children.[11] Finally, the structured days hypothesis[12] posits that school exerts a protective influence on children's obesogenic behaviors and, in turn, children's weight status.[13−28] Specifically, a large and growing body of evidence indicates that children engage in a greater number of behaviors that lead to increased weight gain on days when they are not in school (e.g., weekends and summer) than on days they attend school. Therefore, it is likely that the closure of school buildings for an extended time had negative impacts on children's health behaviors and weight status.[29,30] Indeed, a growing body of literature shows that children's BMI gain accelerates during summer vacation from school.[31−33]

On the basis of this evidence, a recent simulation indicated that BMI z-score (zBMI) gain would increase by up to 0.20 from April 2020 to March 2021 owing to pandemic-related school closures' impact on physical activity levels,[34] and another study estimated a 4.25-percentage point (95% CI=2.90, 5.60) increase in childhood obesity.[29] Furthermore, preliminary, largely self-report studies indicate that children's health behaviors have deteriorated during the COVID-19 pandemic.[9,35−41] Thus, the objective of this study is to evaluate the impact of the COVID-19 pandemic on children's zBMI.

METHODS

This study is consistent with an interrupted time-series design. Time-series data consist of a continuous sequence of repeated observations collected at consistent intervals in a sample of participants.[42] In an interrupted time-series design, the sequence of repeated observations is interrupted by a naturally occurring intervention at a known timepoint.[43,44] In this study, the repeated observations consisted of collecting the heights and weights of all the children at 3 participating schools each fall from 2017 to 2020. The intervention that interrupted this time series was the novel COVID-19 pandemic and the associated mitigation strategies. The participating schools closed on March 16, 2020 and did not reopen until the following school year (i.e., September 9, 2020), and a stay-at-home order was issued by the governor of the state

in which the schools are located on April 7, 2020 and was lifted on May 4, 2020.

Across the 3 schools, there were 2 groups of participants in this study. The first group included children who had their heights and weights collected before and during the COVID-19 pandemic (i.e., children with pandemic measures, *n*=182). The second group was children who only had measures before the COVID-19 pandemic (i.e., children without pandemic measures, *n*=1,588). In this study, the second group (i.e., children without pandemic measures) served as a control to ascertain whether children in Group 1 (i.e., children with pandemic measures) systematically differed from other children in the schools before the COVID-19 pandemic. The number of children measured during each measurement wave is presented in Table 1.

On the basis of this study design, the following hypotheses were generated:

1. Children with and without pandemic measures would have similar yearly changes in zBMI before the COVID-19 pandemic (2017−2019).
2. Children with pandemic measures would experience accelerations in zBMI change during the COVID-19 pandemic (2019 −2020) compared with that during the previous years (2017 −2019).

Study Sample

A total of 3 schools in a single school district in 1 southeastern U. S. state participated in this study. All the children at the participating schools were eligible to participate in this study. Data

Table 1. Number of Children Measured in Each August/September

Group	Sample size	2017	2018	2019	2020
Did not meet inclusion criteria (excluded from analyses)	101	—	—	—	•
Group 1 (children with a pandemic measure)	3	—	•	—	•
	3	•	—	•	•
	38	—	—	•	•
	5	•	—	—	•
	5	•	•	—	•
	59	—	•	•	•
	69	•	•	•	•
Group 2 (comparison)	179	—	•	•	—
	193	—	•	—	—
	205	•	•	—	—
	27	•	—	•	—
	300	—	—	•	—
	340	•	—	—	—
	344	•	•	•	—

collection was conducted each in August/September from 2017 to 2020. Before each data collection wave, a letter with information about the study and data collection protocols was sent home with instructions on how parents could opt for their children not to participate. Children provided verbal assent before each measurement occasion. All protocols were approved by the University of South Carolina IRB. A total of 1,883 unique children attended the participating schools during the 4 years of the study. Children who did not have a measure before the COVID-19 pandemic (*n*=101) and whose parents opted them out of the study (*n*=12) were not included, resulting in a final analytic sample of 1,770 children.

Measures

During regularly scheduled physical education classes, the heights (nearest 0.1 cm) and weights (nearest 0.01 lbs) of the children at the participating schools were measured within the first 3 weeks of the school year (i.e., August/September) 2017, 2018, 2019, and 2020 using a portable stadiometer (Model S100, Ayrton Corp., Prior Lake, MN) and a digital scale (Model 500KL, Health-o-Meter, McCook, IL). Children were instructed to remove their shoes and any heavy outer clothing (i.e., jackets, sweaters). BMI was calculated (BMI=kg/m^2) and transformed into age- and sex-specific z-scores according to the WHO BMI for age growth charts.[45] zBMI is a measure of relative BMI, adjusted for child age and sex, compared with a reference standard (i.e., in this case, it was compared with the WHO BMI for age growth charts). zBMI is necessary for children because they are naturally gaining BMI (i.e., gaining weight and height) as their bodies develop and mature. Thus, a change in zBMI of 0 would indicate that a child has maintained their BMI over time, relative to other children of the same age and sex during the same timeframe, whereas an increase would indicate that their BMI gain has increased more rapidly, and a negative change would indicate that a child's BMI gain has increased less rapidly than those of their same age and sex peers in the reference sample.

Statistical Analysis

All analyses were completed in Stata, version 16.1, during December 2020. Before completing the primary analyses, descriptive means and SDs of school and child characteristics were examined. Children who met the inclusion criteria and had ≥1 valid measure of BMI at any timepoint were included.[46−48] All primary and secondary analyses used maximum likelihood estimators to account for missing data.[49,50] Because data were collected for 2 years before the COVID-19 pandemic (2017−2019), zBMI change was annualized to represent yearly change. Primary analyses were designed to test the yearly change in zBMI before (August/September 2017−August/September 2019) and during the COVID-19 pandemic (August/September 2019−August/September 2020). Multilevel mixed-effects models with measures nested within children and children nested within school were estimated. The dependent variable was yearly zBMI change, and time was the independent variable. Time was dichotomized into before (2017−2019) and during (2019−2020) the COVID-19 pandemic. Secondary logistic regression analyses with the same nesting structure estimated the odds of children being classified as overweight or obese during the year of the COVID-19 pandemic compared with that during the previous years. Sensitivity analyses following the

same modeling techniques but restricted to only children with measures at all timepoints in Groups 1 and 2 (*n*=69 with all measures before and during the COVID-19 pandemic, *n*=344 with all measures before the COVID-19 pandemic only) were also conducted. All analyses controlled for sex, age, race, and baseline level of zBMI. Multiple comparisons were controlled for through the Benjamini−Hochberg procedure with a false discovery rate of 10%.[51]

RESULTS

Descriptive data for the participating schools and children are presented in Table 2. The mean age of the participating children was 8.8 (SD=2.0) years. The sample was primarily Black (63.4%) and was eligible for free or reduced lunches (85.9%). Sensitivity analyses restricted to children with complete data did not differ from the results of the primary and secondary analyses. Therefore, full sample analyses are presented and discussed. Findings from the regression analyses are presented in Figure 1 and Table 3.

Consistent with Hypothesis 1, before the COVID-19 pandemic, children with and those without pandemic measures experienced the same mean yearly zBMI change of 0.03 in the years preceding the pandemic (difference=0.00, 95% CI= −0.09, 0.08). Furthermore, there were no statistically significant or clinically meaningful[52,53] differences between children with and those without pandemic measures in yearly zBMI change before the COVID-19 pandemic by weight status, race, grade, or sex. The remaining analyses were conducted among the sample of children with pandemic measures.

Consistent with Hypothesis 2, children showed a 0.34 increase in zBMI during the COVID-19 pandemic. This represented an acceleration in zBMI change of 0.31 (95% CI=0.19, 0.44) compared with their mean yearly change in zBMI before the pandemic. Correspondingly, children were 1.80 (95% CI=1.40, 2.33) times more likely to be overweight or obese during the COVID-19 pandemic than in previous years.

Next, accelerated zBMI gain by age and sex was examined. Male and female children experienced a 0.29 (95% CI=0.12, 0.46) and 0.33 (95% CI=0.16, 0.50) acceleration in zBMI change during the pandemic, respectively, compared with that in the previous years and were 1.97 (95% CI=1.30, 2.98) and 1.71 (95% CI=1.25, 2.35) times more likely to be overweight and obese during the COVID-19 pandemic, respectively.

Accelerated zBMI gain by race was then examined. Children who are Black experienced a 0.41 (95% CI=0.21, 0.60) acceleration in zBMI change during the pandemic compared with that in the previous years and were 2.57 (95% CI=1.58, 4.19) times more likely to be overweight and obese during the COVID-19 pandemic.

Table 2. Demographic Characteristics of Participating Schools and Children

Characteristics	Participants with prepandemic measures only	Participants with prepandemic and during-pandemic measures
School characteristics		
Total students	1,883	—
% Male	52.6	—
Grades	K–6	—
Race		
% White non-Hispanic	23.9	—
% Black	63.4	—
% Other race (including all races other than Black or White)	12.7	—
% Free or reduced-price lunch	85.9	—
Participant characteristics		
Overall number of participants	1,588	182
% Male	50.1	57.1
Mean grade (SD)	3.2 (2.0)	3.0 (1.7)
Mean age (SD)	8.9 (2.1)	8.5 (1.7)
Race		
% White non-Hispanic	26.1	29.2
% Black	65.2	60.3
% Other race (including all races other than Black or White)	8.7	10.5
Mean BMI z-score		
Fall 2017 (SD)	0.80 (1.20)	0.78 (1.25)
Fall 2018 (SD)	0.80 (1.18)	0.78 (1.20)
Fall 2019 (SD)	0.80 (1.21)	0.80 (1.28)
Fall 2020 (SD)	—	1.16 (1.20)
% overweight or obese		
Fall 2017	44.4	41.5
Fall 2018	42.2	46.7
Fall 2019	42.9	47.3
Fall 2020	—	58.8

K–6, kindergarten−Grade 6.

Similarly, children who are White experienced a 0.22 (95% CI=0.06, 0.39) acceleration in zBMI change during the pandemic compared with that in the previous years and were 2.79 (95% CI=1.07, 7.24) times more likely to be overweight and obese during the COVID-19 pandemic. Children who were identified by their parents to be of other race gained 0.24 (95% CI= −0.10, 0.59) more zBMI during the pandemic than in the previous years and were 1.24 (95% CI=0.85, 1.79) times more likely to be overweight and obese during COVID-19 pandemic.

Accelerated zBMI gain by weight status was examined next. Children who were normal weight before the COVID-19 pandemic experienced a 0.58 (95% CI=0.40, 0.76) acceleration in zBMI change during the pandemic compared with that in the previous years and were 7.50 (95% CI=0.40, 0.76) times more likely to be overweight or obese during the pandemic.

Children who were overweight or obese before the COVID-19 pandemic did not experience accelerated zBMI gain during the pandemic.

Finally, accelerated zBMI gain by grade level was estimated. Lower and upper elementary school children experienced a 0.23 (95% CI=0.08, 0.37) and 0.42 (95% CI=0.22, 0.63) acceleration in zBMI change during the pandemic, respectively, compared with that in the years before the pandemic and were 1.65 (95% CI=1.18, 2.29) and 2.13 (95% CI=1.46, 3.12) more likely to be overweight and obese during the COVID-19 pandemic, respectively.

DISCUSSION

This study examined the impact of the COVID-19 pandemic on children's zBMI through an interrupted time-series study design. Children's zBMI change was
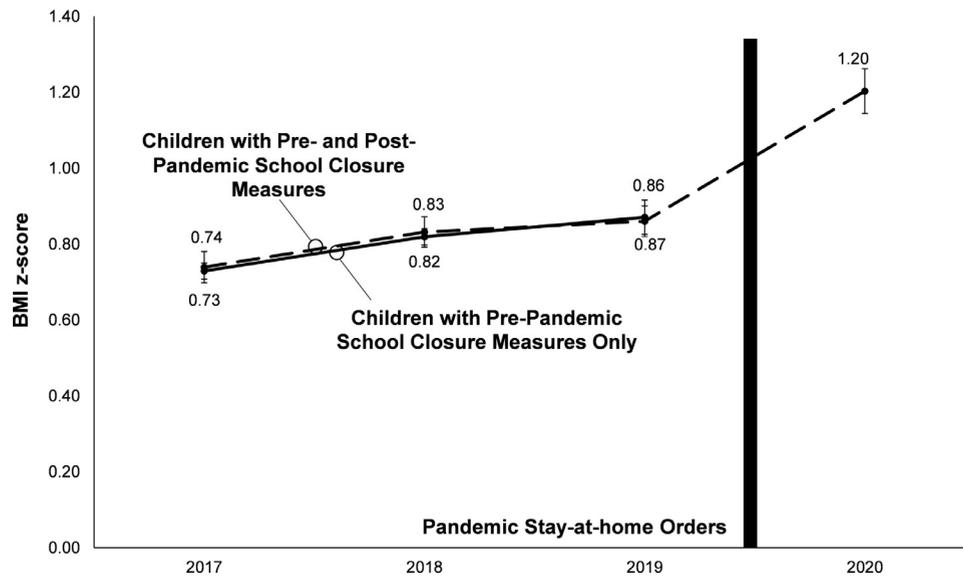
Figure 1. Model estimated the BMI z-score of participants before and after the pandemic school closures.

approximately 10 times greater during the COVID-19 pandemic than in the previous years. Acceleration in zBMI gain was observed across children of different racial groups, grade levels, and sexes. Notably, whereas children who were normal weight experienced significant acceleration in zBMI change, children who were overweight or obese did not. Finally, the accelerated changes in zBMI translated into an increased risk of overweight or obesity.

Although there are a variety of reasons that children's BMI gain increased during the COVID-19 pandemic, the closure of the school buildings was likely a major driver of these increases. The structured days hypothesis posits that the structure (i.e., preplanned, compulsory, adult-supervised activities) provided by schools exerts a positive impact on children's weight-related behaviors (e.g., sleep, diet, physical activity, screen time).[12] During the COVID-19 pandemic, children lost access to regularly scheduled, compulsory physical activity opportunities such as recess and physical education. Furthermore, children no longer had access to meals served at school, which likely increased food insecurity,[6,7] a known risk factor for obesity.[8] Finally, the lack of the school day likely led to variable and later sleep schedules, both of which have been linked to increased risk for overweight or obesity.[54,55]

Preliminary and largely self-reported evidence from around the world indicates that during the pandemic, children were more sedentary, engaged in more screen time[35] and less physical activity,[9,36,37] ate more unhealthy and fewer healthy foods,[9,38] and experienced later and more variable sleep schedules.[39,40] Engagement

in similar behaviors is likely the behavioral mechanism responsible for the accelerated BMI gain in this study.

Although the impact of the COVID-19 pandemic on children's zBMI was not unexpected, the magnitude of the acceleration in change is alarming. Two recent studies have projected the impact of the COVID-19–related school closures on children's zBMI.[30,34] The first study used a microsimulation to estimate the change in zBMI of a nationally representative cohort of kindergarteners from April 2020 to March 2021. In the worst-case scenario (i.e., school closures of 6 months and a 10% reduction in physical activity during the months of summer), the study projected an acceleration in zBMI gain of 0.20 compared with that in the control. The second study took a simpler approach and simply multiplied the mean monthly gain in obesity prevalence of 0.85 percentage points per month (95% CI=0.58, 1.12) observed in a large nationally representative data set[33] and multiplied it by 5 (i.e., the number of months schools were closed). This approach yielded an increase of 4.25 percentage points (95% CI=2.90, 5.60). This study indicates that the accelerations are markedly worse than projected, with an acceleration in zBMI gain of 0.31 from August 2020 to August 2021. This discrepancy may be because both studies only considered the impact of the removal of the school day and did not consider other impacts that the COVID-19 pandemic had on families (i.e., increase in food insecurity, stay-at-home orders, increased reliance on processed foods). Furthermore, the microsimulation study only considered the impact of reduced physical activity while neglecting to consider the impact of the school closures on children's sleep and

Table 3. Yearly Change in zBMI and OWOB in the Overall Sample and by Subgroup

Variable	Children with pre-pandemic measures only — Before pandemic (SE)	Children with pre-pandemic and during-pandemic measures — Before pandemic (SE)	Children with pre-pandemic and during-pandemic measures — During pandemic (SE)	Between group (before pandemic) — Diff (95% CI)	Within group (during pandemic compared with before pandemic)[a] — Diff (95% CI)	Within group (during pandemic compared with before pandemic)[a] — Odds of OWOB (95% CI)
Overall sample	0.03 (0.05)	0.03 (0.06)	0.34 (0.11)	0.00 (−0.09, 0.08)	**0.31 (0.19, 0.44)**	**1.80 (1.40, 2.33)**
Sex						
Male	0.08 (0.08)	0.05 (0.09)	0.34 (0.16)	−0.03 (−0.15, 0.09)	**0.29 (0.12, 0.46)**	**1.97 (1.30, 2.98)**
Female	−0.04 (0.07)	−0.02 (0.09)	0.31 (0.16)	0.02 (−0.11, 0.14)	**0.33 (0.16, 0.50)**	**1.71 (1.25, 2.35)**
Race						
Black	0.10 (0.03)	0.08 (0.06)	0.49 (0.13)	−0.02 (−0.14, 0.10)	**0.41 (0.21, 0.60)**	**2.57 (1.58, 4.19)**
White	0.05 (0.04)	0.03 (0.06)	0.25 (0.13)	−0.02 (−0.15, 0.10)	**0.22 (0.06, 0.39)**	**2.79 (1.07, 7.24)**
Other race	0.03 (0.10)	0.13 (0.15)	0.37 (0.28)	0.10 (−0.21, 0.40)	0.24 (−0.10, 0.59)	1.24 (0.85, 1.79)
Weight status						
Normal weight	0.01 (0.09)	0.00 (0.10)	0.58 (0.18)	−0.01 (−0.15, 0.12)	**0.58 (0.40, 0.76)**	**7.50 (3.09, 18.16)**
OWOB	−0.05 (0.07)	−0.06 (0.08)	−0.05 (0.15)	−0.01 (−0.11, 0.10)	0.00 (−0.14, 0.15)	1.44 (0.44, 4.78)
Grade						
Lower elementary (K–2nd grade)	−0.01 (0.08)	0.02 (0.09)	0.24 (0.16)	0.03 (−0.08, 0.13)	**0.23 (0.08, 0.37)**	**1.65 (1.18, 2.29)**
Upper elementary (3rd–6th grade)	0.11 (0.08)	0.05 (0.10)	0.47 (0.18)	−0.06 (−0.21, 0.09)	**0.42 (0.22, 0.63)**	**2.13 (1.46, 3.12)**

Note: Boldface indicates statistical significance ($p \leq 0.05$).

Change in zBMI of 0 would indicate that a child has maintained their BMI over time, relative to that in other children of the same age and sex during the same timeframe, whereas an increase would indicate that their BMI gain has increased more rapidly, and a negative change score would indicate that a child's BMI gain has increased less rapidly than that of their same age and sex peers in the reference sample.

[a]Diff in yearly zBMI change during pandemic compared with that before the pandemic in children with both prepandemic and during-pandemic measures.

Diff, difference; K–2nd grade, kindergarten–Grade 2; OWOB, overweight or obesity; zBMI, BMI z-score.

diet. Past studies also indicate that school closures and natural disasters disproportionately impact children from minority and low-income households.[56−58] This may partially explain the large magnitude of acceleration in zBMI change in this study given that majority of the sample were from low-income and minority households. Nonetheless, although the magnitude is greater, the acceleration in zBMI gain observed in this study is consistent with simulated projections about the impacts of limited access to school.

Notably, children who were normal weight experienced acceleration in zBMI change, whereas children who were overweight or obese did not. It is possible that children with overweight or obesity were already engaging in risky obesogenic behaviors before the pandemic; thus, behavioral changes were not as dramatic as in children with normal weight, and in turn, BMI gain did not increase as dramatically. However, because behavioral data were not collected, this is speculative. Future studies examining the changes in behavior patterns of children by weight status over the course of this time period might elucidate the mechanisms driving these differences. Furthermore, children who were Black experienced greater accelerations in BMI gain than their White counterparts. The reasons for this are unclear; however, differences in SES may be a mechanism that is driving this difference. Because of structural racism, children from minoritized households are from low-income households at a higher rate than their White counterparts.[59,60] Thus, their families might have been impacted by COVID-19 to a greater degree than the families of children from higher-income and White households for the reasons discussed previously (i.e., school closing and natural disasters disproportionately impact children from minority and low-income households). However, because this study did not collect data on the SES of individuals, it is impossible to disentangle the impact of race and SES on BMI gain in this sample of children during the COVID-19 pandemic.

This study has several strengths that heighten its public health impact. A key strength of this study is the time-series design (i.e., 4 years of measures) and the objective measurement of zBMI. Although several studies examining the impacts of the COVID-19 pandemic have been published in recent months, the vast majority have relied on self-report questionnaires and surveys to measure health behaviors and weight status. The interrupted time-series design also allows for stronger causal inferences to be drawn about the impact of COVID-19 pandemic on the zBMI of children. Furthermore, this study included a large proportion of the children at the participating schools. Thus, the findings are likely representative of the changes in zBMI in these schools and are due to the COVID-19 pandemic.

Limitations

Results from this study should also be interpreted in the context of its limitations. This study was conducted in a convenience sample of 3 schools in 1 southeastern U.S. state and included schools that primarily serve children who are Black and from low-income families; thus, the findings may reflect the significant impact of COVID-19−related school closures on the most vulnerable sector of the population. However, study findings may not generalize to children of other races/ethnicities or from higher-income populations. Furthermore, only 182 children had measures before and during the COVID-19 pandemic. Although repeated and objective measurement of zBMI is a relative strength of this study, it is worth noting that this study is limited by the lack of contextual measures beyond zBMI. Changes in BMI are driven by a complex web of behavioral, environmental, and biological factors. The lack of such measures does not allow for this study to examine the mechanisms responsible for these dramatic changes in zBMI. However, given the recent proliferation in COVID-19 studies published in the past year, it is likely that additional high-quality research regarding the behavioral impacts of COVID-19 will help contextualize the findings of this study.

CONCLUSIONS

The findings from this study indicate that children's zBMI gain increased dramatically during the COVID-19 pandemic. These findings are alarming given the magnitude of change in zBMI and underscore the urgent need for public health interventions to address overweight and obesity, especially in children from minority and low-income families.

ACKNOWLEDGMENTS

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