Physical fitness among children with diverse weight status during and after the COVID-19 pandemic: a population-wide, cohort study based on the Slovenian physical fitness surveillance system (SLOfit)

Antonio Martinko,[a,*] Maroje Sorić,[a,b,**] Gregor Jurak,[b] and Gregor Starc[b]

[a]Faculty of Kinesiology, University of Zagreb, Zagreb, Croatia
[b]Faculty of Sport, University of Ljubljana, Ljubljana, Slovenia

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Summary

Background COVID-19 public health crisis has exerted immediate negative impacts on children's physical fitness, but the longer-term effects are not clear, and the impact on children with excess weight is yet unknown. We examined changes in multiple components of physical fitness in response to COVID-19 imposed restrictions, but also a year after the restrictions were terminated, and compared these trends in groups of boys and girls with normal weight, overweight, or obesity before the pandemic.

Methods Information was gathered through Slovenia's national fitness surveillance system, and included 41,330 children (19,890 girls), aged 5–17, who had their fitness levels measured yearly from 2019 to 2022. Multilevel linear mixed models, fitted separately for boys and girls, were used to model the individual-level trends over time in centile score for each fitness test across 3 weight groups.

Findings Overall fitness levels decreased markedly across all weight categories between 2019 and 2020, with the largest decreases in Total Fitness Index observed in children with normal weight and overweight (−8.4 and −7.7 centiles for boys and −8.3 and −8.8 for girls, respectively, $p < 0.001$). While there was some recovery in the overall fitness level between 2020 and 2022, it remained much lower in 2022 compared to 2019 across most groups, apart from boys with obesity. Fitness components that had the largest impact on general fitness trends were cardiorespiratory fitness, lower body power, body core, and upper body strength.

Interpretation A severe decline in fitness that has not come close to returning to pre-pandemic levels in most population groups of youth begs for urgent population-wide initiatives that will provide additional opportunities for physical activity to youth. Among vulnerable groups, girls with overweight and obesity deserve a special focus of these policies.

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Introduction

Physical fitness is a good indicator of health in childhood and adolescence and can be used as a predictor of future health.[1] Children who maintain high levels of physical fitness are less likely to suffer from chronic diseases such as obesity, type 2 diabetes, and cardiovascular disease.[1–3] Furthermore, physical fitness has been linked to improved academic performance, better cognitive function, and reduced symptoms of anxiety and depression.[4–6] Studies on physically fit children have also shown that they are more willing to engage in, enjoy and maintain physical activity and that this also encourages them to participate and excel in physical activity of various levels.[7]

*Corresponding author.
**Corresponding author. Faculty of Sport, University of Ljubljana, Ljubljana, Slovenia.
E-mail addresses: antonio.martinko@kif.unizg.hr (A. Martinko), maroje.soric@fsp.uni.lj.si (M. Sorić).

Research in context

Evidence before this study

Restrictions imposed during the pandemic were detrimental regarding behaviours of children, where they were less likely to be physically active, more likely to spend more time in front of screens, and sleep longer than before the lockdown. We reviewed the literature published in all languages between January 1, 2020 and June 1, 2023, in several databases (MEDLINE, Scopus, and Web of Science), incorporating terms relating to: COVID-19 (covid* OR coronavirus OR sars-cov-2* OR pandemic); trends (trend* OR impact* OR influence); children or adolescents (child* OR adolescen* OR young OR youth* OR teen*); and physical fitness (fitness OR fit*). In a secondary search, we also searched through the reference lists of all relevant studies we identified in the primary search. Based on our review of the literature published and to our knowledge, there are currently only a few studies that analysed physical fitness changes among children both during and after COVID-19 restrictions, but most of them stopped examining short-term consequences of COVID-19 related restrictions immediately after they ended. Moreover, typically only one or very few components of physical fitness were studied and there were no attempts to examine inequalities in physical fitness based on weight status. Therefore, the main aim of this study was to examine changes in multiple dimensions of objectively measured physical fitness in response to COVID-19 imposed restrictions, but also a year after the restrictions were terminated, and to examine weight-based inequalities in health by comparing physical fitness trends in groups differing by weight status before the pandemic.

Added value of this study

A longitudinal study of a large sample of 41,330 children from all regions of Slovenia, with physical fitness assessed yearly over four time points, allowed for generalizability as well as robust conclusions about the short- and mid-term impact of COVID-19 restrictions on physical fitness in children. The focus of the study on children is also important because physical fitness during childhood is related to physical, mental, and cognitive health, and is a strong predictor of immediate and distant health outcomes. The inclusion of different weight status groups adds to the strengths of the study because physical fitness changes were assessed in children with normal weight, overweight, and obesity before the pandemic, which provided insight into how the pandemic has impacted weight-based inequalities in health.

Implications of all the available evidence

We provided a comprehensive analysis of the temporal trends of different physical fitness components among children of diverse weight status during and after the COVID-19 pandemic. Our findings add to the evidence on a large decrease across the spectrum of fitness components during the pandemic. We have identified diverging trends in physical fitness in the aftermath of COVID-19 across weight groups, sex, and fitness components. As we observed incomplete recovery from the decrease in physical fitness witnessed during the restriction measures in most groups of children, no targeting is advisable at this time and population-based initiatives are warranted instead. Still, by providing data for sex and weight-based groups, our findings can enable policymakers and public health officials to tailor more effective interventions aimed at improving physical fitness adapted to specific groups of children, with a special need to focus on vulnerable groups of children, i.e., girls with overweight or obesity. These urgently needed responses could include a wide range of initiatives. Promoting enjoyable physical activity and healthy eating and sleep habits, as well as introducing measures to reduce sedentary behaviour and screen time, providing ample opportunities to be active, and developing physical literacy are only some of them.

While the COVID-19 pandemic has affected many aspects of daily life, the impact on children's physical activity and physical fitness has been particularly concerning, as they navigated the challenges of social distancing, remote learning, and limited access to outdoor spaces and recreational activities.[8–10] In response to the pandemic, many European countries have imposed similar restrictions to the rest of the world. Slovenia might be particularly interesting since it is regarded as one of the countries with the highest levels of overall physical activity and physical fitness of children.[11] Some of the hypothesised reasons include systematic surveillance of physical fitness during childhood, supportive community and environmental factors and quality physical education in schools.[11] First declared measures in Slovenia shut down kindergartens, schools, and universities, and prohibited entrance to open playgrounds, sports parks, sport training camps, and public transportation. Schools were closed and organized sports activities for children under the age of 15 were not allowed during the period from October 2020 to February 2021, when they were reopened for all children. During this time, teachers provided online instructions to students via text or videos, while physical education sessions were also delivered live, via video call. As a response to the declared measures, Slovenia was one of the first countries to immediately publish physical activity guidelines and implement some other measures to promote physical activity at this time.[12–15] Restrictions imposed during the pandemic were detrimental regarding behaviours of children, where they were less likely to be physically active, more likely to

spend more time in front of screens, and sleep longer than before the lockdown.[8,16–18] The long-term consequences of this unprecedented natural experiment are still to be unravelled. These could be especially important for vulnerable groups of children, such as children with obesity. Obesity in childhood and adolescence is detrimental to both the physical and mental health of youth.[19–21] Studies that have examined the so-called "fat but fit" phenomenon in children have documented that higher fitness mitigates some of the negative effects of obesity, being associated with better cardiometabolic health,[22,23] and general well-being.[24] For a condition in which obesity coexists with a fully healthy metabolic profile that is present in 10–30% of adults and in 6–36% of children/adolescents, the conclusion that obesity (but also for the metabolically unhealthy phenotype) is associated with a higher risk of all-cause, CVD and cancer mortality is modified (i.e., no difference is present in the prognosis between metabolically healthy but with obesity and metabolically healthy but with normal weight individuals) when cardiorespiratory fitness is accounted for.[25]

To our knowledge, there are currently only a few studies that analysed physical fitness changes among children both during and after COVID-19 restrictions.[26–35] These studies agree that cardiorespiratory fitness,[26–30,32,33,35] lower body explosive power,[27,28,33,35] and speed decreased,[28,32] after COVID-19 containment restrictions, while more generally, a lower share of participants was meeting the recommended physical fitness levels.[29,33,35] Conflicting evidence was reported regarding other components of muscular fitness. For the aftermath period, an interesting analysis from Germany showed that children in cohorts 2020–2022 were estimated to exhibit developmental delays of approximately 5 months in cardiorespiratory fitness, 3 months in coordination, and 1 and 2 months in speed and upper body strength, respectively.[34] Contrastingly, there were some components where they were advanced, i.e., approximately 1 month in terms of lower body strength and 7 months in advance in developing static balance.[34]

However, most of these previous studies stopped at examining the short-term consequences of COVID-19 related restrictions immediately after they ended. Moreover, typically only one or very few components of physical fitness were studied and there were no attempts to examine inequalities in physical fitness based on weight status. Therefore, the main aim of this study was to examine changes in multiple dimensions of objectively measured physical fitness in response to COVID-19 imposed restrictions, but also a year after the restrictions were terminated, and to examine weight-based inequalities in health by comparing physical fitness trends in groups differing by weight status, i.e., children with overweight or obesity, vs. their peers with normal weight before the pandemic. As the COVID-19 public health crisis led to societal changes of unprecedented scope and intensity, and as there are no studies on the lingering effects of the recent pandemics on fitness, it is not possible to generate hypotheses based on prior data. Yet, given that children with excess weight have lower levels of habitual activity and lower levels of participation in vigorous physical activity,[36] their lifestyle was less affected by the diminished opportunities for physical activity during the pandemic. Therefore, we hypothesised that the expected physical fitness will be lower for children with overweight and obesity. On the other hand, because of less frequent participation in physical activity,[36] lower intrinsic motivation for physical activity,[37] and lower self-efficacy[38] of children with overweight and obesity, we hypothesised that these groups would exhibit less post-pandemic fitness catch-up.

Methods

Study design, participants, and measurements

This study utilized a large dataset collected through the SLOfit system[39] to conduct a population-based study. We included 41,330 children (girls: 19,890, 48%), aged 10.7 ± 2.1 years (range: 5–17), who had their fitness measured annually from 2019 to 2022. The SLOfit surveillance system involves more than 200,000 children every year, which constitutes >94% of all children in the primary school population (6- to 14-year-olds) and over 75% in the secondary school population (15- to 19-year-olds). However, due to difficulties in data collection during 2020 and 2021, a retrospective cohort in this study included about 25% of the total population of 6–17-year-old children living in Slovenia in 2019. We have compared the characteristics of the sample against the population at baseline (in 2019) and found that the sample can be considered representative of the population. We found that the regional and sex distribution of the analysed sample was very similar to the population regional and sex distribution. We also found that regarding weight status categories and average physical fitness the sample closely resembled the population. Children from the sample were on average just one month younger than the population and had 0.13 kg/m^2 lower BMI. The SLOfit system includes various fitness tests, such as body mass index (BMI), triceps skinfold, 600-m run, 60-s sit-ups, bent-arm hangs, stand-and-reach, standing broad jump, backwards obstacle course, 60-m dash, and 20-s arm plate tapping. When summarising the results, we divided physical fitness into two widely acknowledged domains. Within the health-related fitness domain, we included body composition (BMI and triceps skinfold), cardiorespiratory fitness measured by the 600-m run test, and muscular fitness represented by 60-s sit-ups, bent-arm hangs, and standing broad jump tests. On the other hand, the skill-related fitness domain in this study included speed, neuromuscular, and gross-motor coordination, tested by 60-m dash, 20-s arm plate tapping,

and backwards obstacle course, respectively. Raw results of all tests were converted to centile values based on the Slovenian national fitness standards.[40] We then averaged centile values of all 10 fitness tests to obtain an aggregated measure of physical fitness—Total Fitness Index. We divided participants into three distinct weight groups by comparing their BMI noted in 2019 to the age and sex-specific Slovenian national standards.[40] Obesity classification was assigned when the centile value exceeded 95, and overweight in case the centile value was >85. All other values were classified as normal weight. All measurements were conducted in schools while respecting general anti-epidemic measures (i.e., social distancing, disinfection, air ventilation) and all testing protocols were identical across all four assessment waves. More details on test protocols and how outliers were treated can be found elsewhere.[41]

Due to the need to address the biologically implausible values in anthropometric data (height, weight, BMI), previously determined criteria were used. This may be of particular concern because measurements were collected in non–research settings, i.e., schools. Biologically implausible changes over time, such as weight loss/gain and shrinking/large height changes were flagged based on the widespread method constructed on World Health Organization recommendations. Based on these recommendations, all weight values that were either –5.0≤ or ≥5.0 weight for age z-scores, height values that were either –5.0≤ or ≥3.0 height for age z-scores, and weight for height or BMI values that were either –4.0≤ or ≥5.0 weight for height or BMI z-scores were flagged. For this purpose, the AnthroPlus package[42] was used, and after flagging 107 values, one researcher (AM) manually checked them, and 72 of those values were deemed plausible based on consistent serial measurements, while a joint decision was needed for 35 of those values. After a joint review of those values (AM + MS), only 1 of those 35 was kept for the final analyses and 34 were deemed implausible and were, hence, completely omitted from the analysis.

Statistical analysis

We used multilevel linear mixed models to analyse individual-level trends over time. We stratified all analyses by sex due to well-documented sex differences in fitness, with girls exhibiting lower levels of most components of physical fitness, as well as different patterns of fitness development throughout childhood and adolescence.[43] In the multilevel framework, several models were constructed and compared with the likelihood ratio test and by comparing the Akaike Information Criteria (AIC) values of the models to find the final model.[41] Due to stratified analyses and consequently a large number of models, the final models (based on the optimal fit statistic) for each outcome are presented in Supplementary Material (Supplementary Tables S6 and S8–S16). The final models were then used to estimate the changes in outcomes in time stratified by sex, considering the centile for each test score as a dependent variable, and year (as a categorical factor, using 2019 as a reference), age (in months), and weight status (normal, overweight, obesity) as predictors, including in the model also the year and weight status interaction. Also, the final models considered different variance structures for different groups of participants based on their weight status and in subsequent years. Sensitivity analyses were also conducted where the height percentile, centred to the mean of each participant, was included as a covariate to control for differences in growth and maturation. This was considered important since we analysed trends in children across weight status groups, and it has been reported that children with obesity tend to mature earlier than peers with normal weight.[44] Only the estimates from the final models are reported in the results section, while all other information and a longer, and more detailed report of the methodological considerations are available in the Supplementary Material. Statistical significance was set at $p < 0.05$.

All statistical analyses were performed with R version 4.3.0.

Role of the funding source

The funding bodies had no involvement in study design; collection, management, analysis, and interpretation of data; in the writing of the report; or the decision to submit for publication.

Results

The number of participants across years on all levels of interest and participant characteristics are detailed in Supplementary Table S2 while participants' characteristics are given in Supplementary Tables S4 and S5, and Supplementary Figures S2–S16. Temporal trends and differences in Total Fitness Index centile values of Slovenian boys and girls, across weight status groups and adjusted for age during and after the COVID-19 pandemic (2019–2022) are available as a part of the Supplementary Material.

For aggregated physical fitness, comparable magnitudes of both downward and upward trends in the Total Fitness Index were noted among boys with normal weight and overweight, but not in boys with obesity (Supplementary Figure S1). First, a similar sharp drop was seen in both boys with normal weight and overweight in 2020 (–8.4 and –7.7 centiles, respectively). Between 2020 and 2021, the Total Fitness Index recovered only mildly (0.4 and 1.4 centiles, respectively), while between 2021 and 2022 that recovery was 4.2 and 4.2 centiles, respectively (all $p < 0.001$). After this recovery period, Total Fitness Index values of children with normal weight and overweight still end up at a much lower level in 2022 vs. 2019. Boys with obesity

exhibited a smaller decrease in average Total Fitness Index centile compared to other groups (–3.7, $p < 0.001$), but achieved comparable recovery in the next 2 years that resulted in almost identical levels of Total Fitness Index in 2022 in this group as in 2019. Between-group differences in temporal trends in aggregated physical fitness for girls are depicted in Supplementary Figure S2. While patterns were similar in girls with normal weight and overweight, girls with obesity exhibited a smaller decrease in average Total Fitness Index centile compared to their peers with normal weight (–5.8 vs. –8.8, $p < 0.001$), but also a less pronounced recovery afterwards. Compared to girls with normal weight, the Total Fitness Index values of girls with obesity recovered less between 2020 and 2021 (0.6 vs. 2.3 centiles, respectively).

Health-related physical fitness

For body composition (Fig. 1 upper and middle pane), similar trends were observed among both boys and girls with overweight and obesity, with little change over time. At the same time, boys and girls with normal weight exhibited an increase in average BMI centile with a large initial increase between 2019 and 2020 (4.4 and 4 centiles, respectively), a slightly smaller increase between 2020 and 2021 (by 2.5 and 1.8 centiles, respectively), followed by a decrease between 2021 and 2022 that was more pronounced in boys (–3.2 and –1.8 centiles, respectively) (all $p < 0.001$). Very similar patterns were also observed for triceps skinfold apart from an important decrease in all weight groups between 2021 and 2022 amounting to –2.0, –3.9, and –4.3 centiles in boys with obesity, overweight, and normal weight, respectively, while totalling around –2 to –3 centiles in all groups of girls. Over the whole period, both BMI and triceps skinfold decreased in children with overweight and obesity but increased in children with normal weight (Supplementary Figures S19–S22 in Supplementary Material). The results corresponding to the final models for BMI and triceps skinfold can be seen in Supplementary Tables S8 and S9, respectively, in the Supplementary Material, the Final models results section.

In terms of cardiorespiratory fitness (Supplementary Figures S23 and S24 in Supplementary Material), the direction of trends was identical across weight groups and sex, but the magnitude of changes differed between groups. Average cardiorespiratory fitness centile values for boys with normal weight and overweight initially dropped sharply (–9.9 and –7.8, respectively, $p < 0.0001$), while boys with obesity showed a much lower drop (–2.9 centiles, $p = 0.0002$). No change was seen from 2020 to 2021, while between 2021 and 2022 cardiorespiratory fitness recovered in boys with normal weight, overweight, and obesity (5.5, 5.7, and 3.6 centiles, respectively, all $p < 0.001$), which still left boys with normal weight and overweight with lower levels of cardiorespiratory fitness in 2022 than before restrictions. In contrast, boys with obesity ended up with a higher average cardiorespiratory fitness centile value in 2022 compared to 2019 (Fig. 1 bottom pane). In girls, identical patterns of change across weight groups were observed for 2019–2020 and 2020–2021 as described for boys. Conversely, between 2021 and 2022 cardiorespiratory fitness recovered only in girls with normal weight and overweight (2.6 and 3.0 centiles, both $p < 0.001$), but not in girls with obesity (1.0 centile, $p = 0.48$), which left all groups of girls with lower levels of cardiorespiratory fitness in 2022 than in 2019 (Fig. 1 bottom pane). The results corresponding to the final models for cardiorespiratory fitness can be seen in Supplementary Table S10 in the Supplementary Material, in the section Final models results.

Muscular fitness

Trends in several muscular fitness components across weight groups and sex are depicted in Fig. 2. The results corresponding to the final models for body core strength, upper body strength, and lower body power can be seen in Supplementary Tables S11–S13, respectively, in the Supplementary Material, the Final models results section. For body core strength, we found a more pronounced initial decline in boys with overweight and obesity (–8.3 and –9.1 centiles, respectively) compared to boys with normal weight (–4.7 centiles) and in girls, a more pronounced initial decline was seen in girls with obesity (–9.2 centiles) compared to those with normal weight and overweight (–6.2 and –6.9 centiles, respectively) (all $p < 0.0001$). After this initial decline, changes were similar across groups and sex. For boys with normal weight and overweight, non-significant changes were seen between 2020 and 2021 followed by an increase between 2021 and 2022 (2.2 and 2.4 centiles, respectively, both $p < 0.0001$). No changes in body core strength between 2020 and 2022 were seen in boys with obesity. Similar patterns were detected in girls, with the difference in the overweight group mirroring trends seen in the obesity group.

For upper body strength, we observed a sharp initial decline in boys with normal weight and overweight (–5.9 and –5.3 centiles, respectively), but not in boys with obesity. In the second year of the pandemic, upper body strength decreased further only in boys with normal weight (–1.1, $p < 0.0001$). After restrictions had ended, upper body strength recovered in all groups of boys, although this recovery was more pronounced in boys with normal weight and overweight (3.6 and 4.0 centiles, $p < 0.0001$), compared with boys with normal weight (1.6 centiles, $p = 0.004$). In girls, an initial decline was seen in all groups but was much less pronounced in girls with obesity (–6, –4.5 and –2.1 centiles for girls with normal weight, overweight, and obesity, respectively; $p < 0.0001$ for girls with normal weight and overweight; $p = 0.003$ for girls with obesity). This was followed by no change between 2020 and 2021. After the

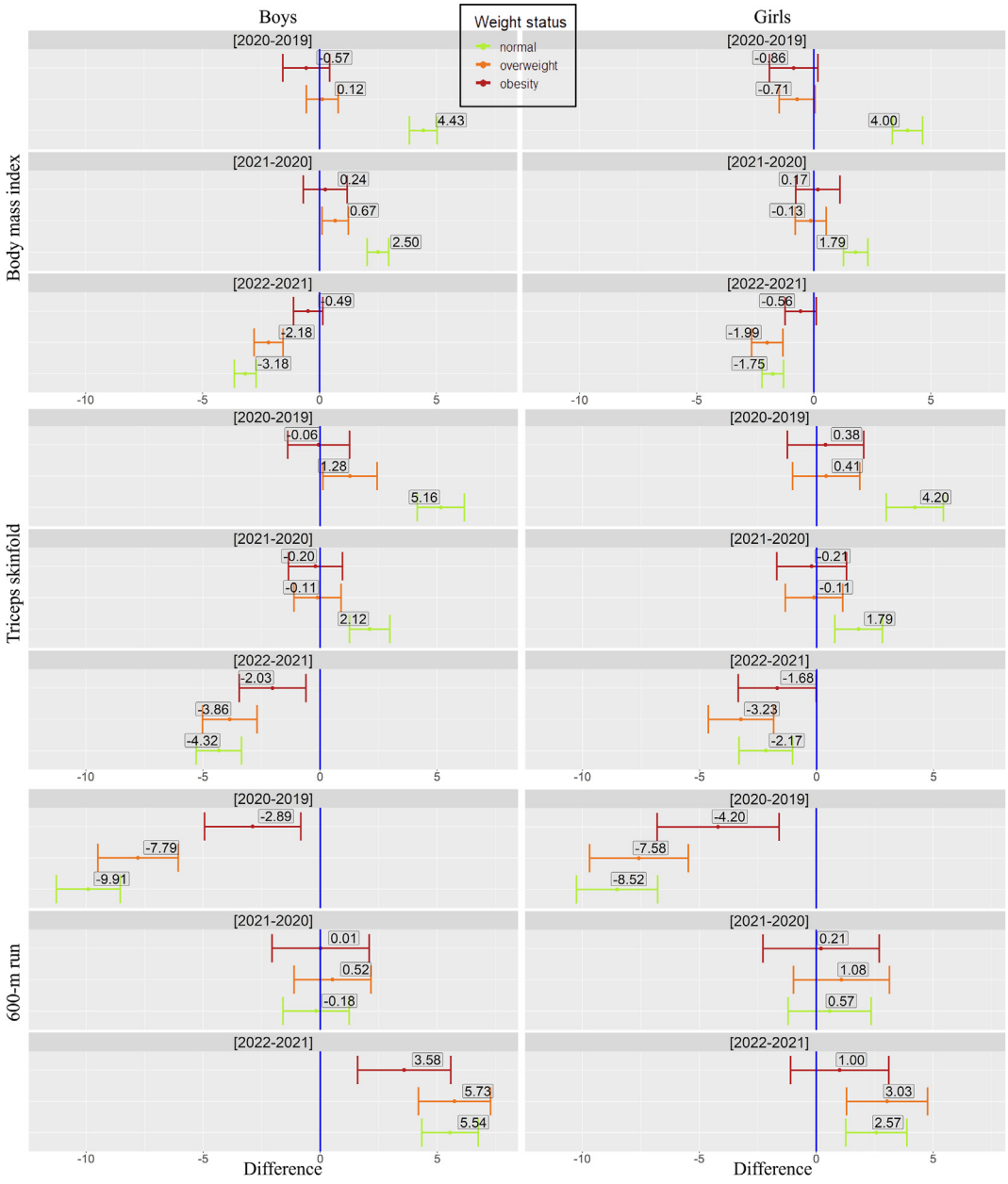

Fig. 1: **Temporal trends and differences in body composition (BMI and triceps skinfold) and cardiorespiratory fitness (600-m run) of Slovenian children across weight status groups during and after the COVID-19 pandemic (2019–2022).** Body mass index (BMI) is depicted in the upper pane, triceps skinfold in the middle pane and cardiorespiratory fitness (600-m run) in the bottom pane. Data show differences in means across years estimated by mixed regression models adjusted for age.

restrictions had ended average centile values increased among girls with normal weight and overweight by 2.1 and 2.5 centiles, respectively (both $p < 0.0001$), but failed to rebound among girls with obesity.

Initial declines were smaller for lower body power than for other components of muscular fitness and comparable between weight and sex groups. After that period lower body power did not change much in girls, while a slight rebound in boys was seen after 2021 that amounted to cca 2 centiles and was similar across weight groups ($p < 0.0001$ for normal weight and overweight, and $p = 0.001$ for obesity, respectively). Lower body power did not change after 2020 among girls in any of the groups.

Over the whole period, trends in muscular fitness differed depending on the component (Supplementary

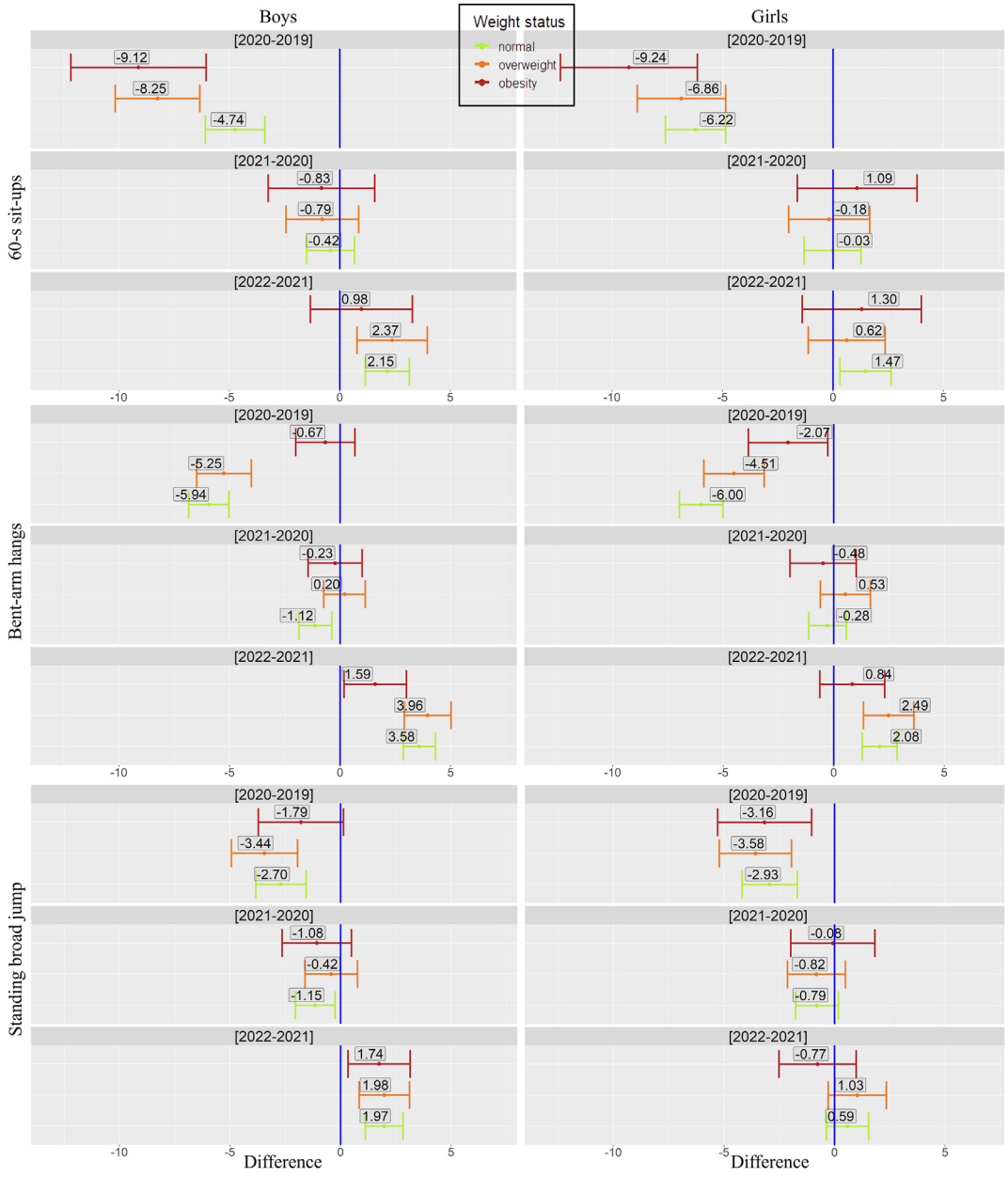

Fig. 2: **Temporal trends and differences in muscular fitness of Slovenian children across weight status groups during and after the COVID-19 pandemic (2019–2022).** Body core strength (sit-ups) is depicted in the upper pane, upper body strength (bent arm hang) in the middle pane and power of lower body (standing long jump) in the bottom pane. Data show differences in means across years estimated by mixed regression models adjusted for age.

Figures S25–S30 in Supplementary Material). Body core strength decreased dramatically and remained at much lower levels in 2022 compared to the pre-pandemic period, the difference being much larger for children with overweight and obesity than for their peers with normal weight. In contrast, upper body strength did not reach full recovery only in children with normal weight and was not much lower in 2022 compared to pre-pandemic levels in children with overweight or obesity. Finally, lower body power rebounded almost to pre-pandemic levels in boys but ended up at much lower levels in girls across all weight groups.

Skill related fitness

Trends in three skill-related physical fitness components across weight groups and sex are illustrated in Fig. 3.

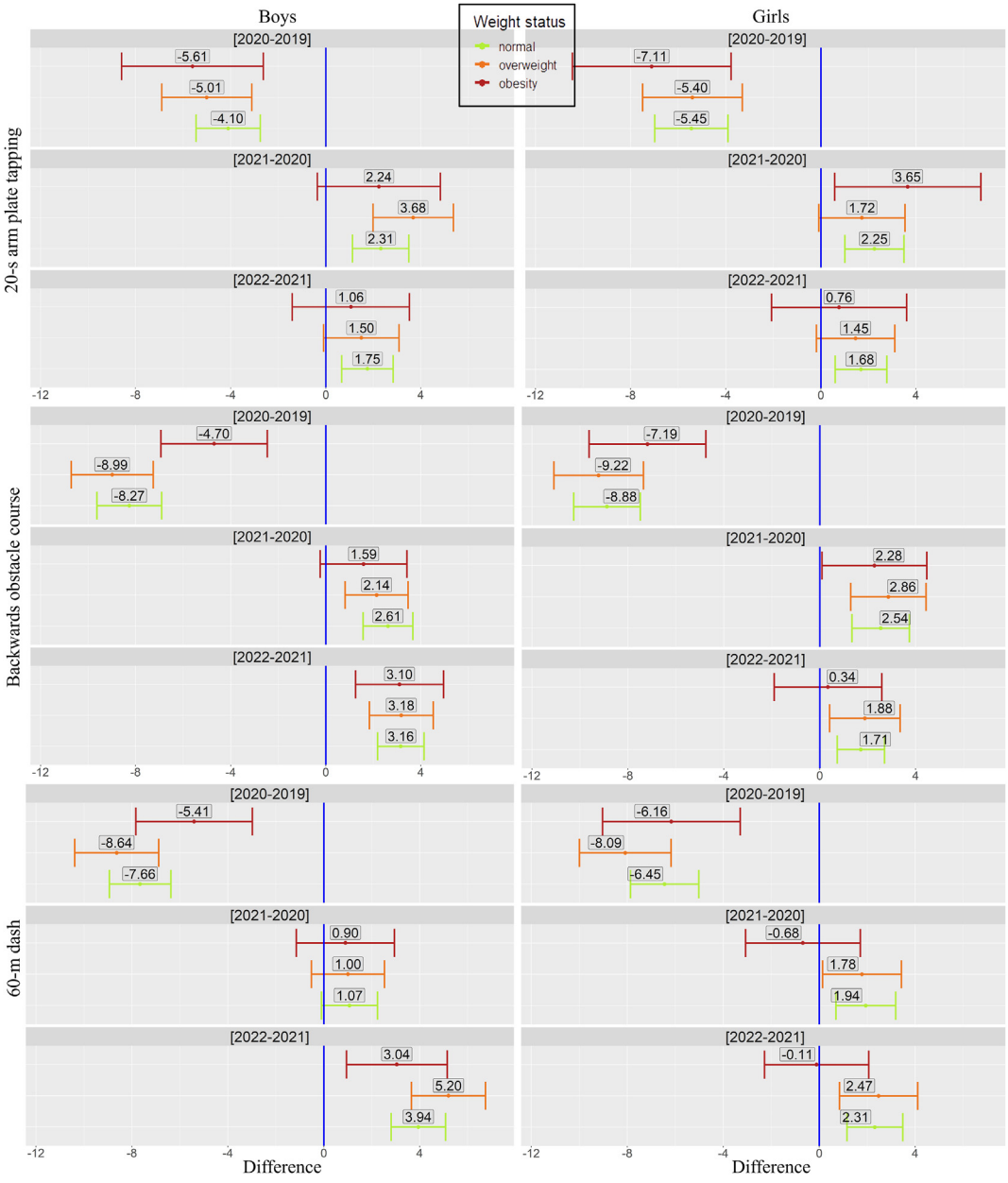

***Fig. 3*: Temporal trends and differences in skill related fitness of Slovenian children across weight status groups during and after the COVID-19 pandemic (2019–2022).** Neuromuscular coordination (arm plate tapping) is depicted in the upper pane, gross motor coordination (backwards obstacle course) in the middle pane and speed (60-m dash) in the bottom pane. Data show differences in means across years estimated by mixed regression models adjusted for age.

The results corresponding to the final models for neuromuscular coordination, gross motor coordination, and speed can be seen in Supplementary Tables S14–S16, respectively, in the Supplementary Material, the Final models results section.

For neuromuscular coordination, initial declines were the largest in boys and girls with obesity (–5.6 and –7.1, respectively, $p < 0.001$), but were also present in all other groups where they ranged from –4.1 to –5.4 centiles. These declines were followed by a comparable recovery over the next two years in boys and girls with normal weight and overweight, while the rebound in children with obesity was less evident.

During the first year of the pandemic, gross motor coordination fell sharply by –7.2 to –9.2 centiles in all groups except for boys with obesity who witnessed a

twice lower drop (–4.7 centiles, all $p < 0.0001$). After this, a clear recovery was seen in all weight and sex groups, albeit least marked in girls with obesity.

Speed initially dropped sharply for all weight and sex groups, and then rebounded over the next 2 years in all groups apart from girls with obesity. The initial drop ranged from –5.4 centiles in boys with obesity to –8.6 centiles among boys with overweight, while recovery in the period 2021–2022 ranged from 2.3 centiles in girls with normal weight to 5.2 centiles in boys with overweight (all $p < 0.001$).

Over the whole period, weight-based trends in skill-related fitness differed depending on the component (Supplementary Figures S31–S36 in Supplementary Material). Neuromuscular coordination recovered completely in boys, and to a large extent in girls without differences between weight groups. Gross motor coordination and speed recovered only in boys with obesity, remaining at lower levels compared to the pre-pandemic period in all other groups of children. The 2019–2022 gap was especially pronounced for speed among girls with obesity (–7.0 centiles).

Sensitivity analyses

As stated previously, we also conducted sensitivity analyses where the height percentile, centred to the mean of each participant, was included as a covariate to control for differences in growth and maturation. We included the results of this additional analysis for the Total Fitness Index in the Supplementary Material (Supplementary Table S7, Supplementary Figures S37 and S38) as an example to demonstrate the robustness of the study findings. As the results of these models were not noticeably different from the main analyses, only results from the final models are reported in detail.

Discussion

We followed a cohort of >41,000 children, aged between 5 and 17, over 3 years to examine changes in multiple components of physical fitness in response to COVID-19 restrictions and a full year after the restrictions were lifted, and to compare these trends in groups differing by weight status before the pandemic. COVID-19 restrictions had a very large, but non-uniform impact on physical fitness, that varied by initial weight status and by fitness component. We saw that physical fitness, including body composition, cardiorespiratory, muscular, and skill-related fitness, deteriorated dramatically between 2019 and 2020 across all groups and in both sexes. However, the drops in physical fitness were smaller in individuals with obesity compared to their peers with normal weight, or overweight, with the only exception being body core strength which was affected more in children with obesity. We also found that although a rebound was noted for all physical fitness components after 2021, it was incomplete in most groups, which left the physical fitness of children with normal weight and overweight, and girls with obesity at a lower level in 2022 compared to 2019. On the other hand, boys with obesity regained their global physical fitness, on account of improving their body composition, exceeding their baseline levels of cardiorespiratory fitness, and almost completely retrieving their skill-related fitness, upper body power, and lower body power strength, while only their body core strength ended up much lower a year after the end of restrictions. These patterns of change are consistent with previous research that has shown that prolonged periods of inactivity can have negative effects on physical fitness. Importantly, we observed that the decreases in physical fitness during COVID-19 restrictions were smaller in individuals with obesity compared to their peers with normal weight. This is an interesting finding, as it suggests that children with obesity may have been more resilient to the negative effects of the pandemic on physical fitness. However, it is important to note that individuals with obesity are typically less active and less fit to begin with, which has probably contributed to the smaller relative decreases in physical fitness. On the other hand, pandemic-related decrease in health-related fitness in children with overweight was of similar magnitude as in their peers with normal weight, while the decrease in skill-related fitness was generally even larger in the group of children with overweight group of children despite their much lower initial level of physical fitness.

Numerous studies have analysed the effects of COVID-19 restrictions on physical fitness, although most focused on immediate effects. These studies included children and adolescents of different ages (7–18 years old) and covered various geographical regions across the globe, i.e., Austria,[27] China,[32] England,[26] France,[28,33] Germany,[34,45] Portugal,[30] Singapore,[31] South Korea,[35] and Spain,[29] indicating a global representation of research on the impacts of COVID-19 restrictions on physical fitness. Sex distribution was also considered in some studies,[27–29,32,34,35] with findings suggesting potential sex-based differences in physical fitness outcomes. Overall, previous studies indicated increased BMI among children after COVID-19 containment restrictions,[26,27,30–33] decreased cardiorespiratory fitness,[26–30,32,33,35] lower body explosive power as a component of muscular fitness,[27,28,33,35] lower speed,[28,32] and generally lower share of participants meeting recommended physical fitness levels.[29,33,35] Conflicting evidence exists regarding other components of muscular fitness such as pull-ups,[32] push-ups and sit-ups,[45] medicine ball push, throw-and-catch performance, arm-plate tapping,[27] and handgrip strength.[26] Overall, our findings from Slovenia corroborate existing evidence on the global negative effects of COVID-19 related restrictions on children's physical fitness, although some variations exist across different dimensions of physical fitness. While the decline in physical fitness observed in our study was universal

across all fitness components, it was somewhat less pronounced for lower body power in both sexes. All in all, this suggests the need for exercise programmes and physical activity policies that target all components of physical fitness in the aftermath of the COVID-19 pandemic.

We are not aware of the prior studies that considered weight-based inequalities in terms of COVID-19 restriction consequences on fitness. Only one study considered BMI percentile as a covariate in their analyses and determined that their results remained essentially unchanged, except for the countermovement jump.[27] In our study notable differences in trends were observed for children of differing weight status. Children with obesity had poor initial physical fitness and were much less affected by COVID-19 related restrictions, possibly because their lifestyle did not change that much. On the other hand, while boys with obesity quickly regained their fitness, girls with obesity were not successful in cancelling the pandemic-related effects for almost any fitness component, and the gap remained the largest for muscular fitness, gross motor coordination, and speed. The reasons for this sex difference could not be analysed in our study and need to be examined in future studies. Children with normal weight and overweight were still quite behind their pre-pandemic physical fitness in 2022 in this study, but since they had only one year to recover it might be too early to say that the pandemic will have long-term effects on physical fitness. All in all, population-wide measures and ample opportunities for physical activity fit to all children seem urgently needed. Although it is not advisable for these policies to single out specific groups, they should be designed to contain elements that will guarantee stronger engagement of girls with excess weight as a high-risk group that obviously struggles with regaining fitness in the post-pandemic era.

We found no substantial between-sex differences in trends for immediate fitness change driven by anti-epidemic measures. On the contrary, several recent studies that have examined changes in physical fitness in response to COVID-crisis found more pronounced deterioration in girls compared to boys.[27,28,34] On the other hand, we found that the recovery of fitness was much smaller in girls and left them with more visible pandemic effects in 2022. This sex difference was seen for most fitness components and across all-weight groups but was especially pronounced in children with overweight and obesity. The sex gap in physical activity is well documented.[46] Girls are not only less active but usually experience less enjoyment from physical activity and have lower confidence in their sporting abilities.[47] When designing and implementing physical activity policies to counter the negative effects pandemics have had on physical fitness, policymakers should take special care about the types of activities offered to promote female participation and ensure sex equality.

This is one of the first studies that examined the longer-term impacts of imposed restrictions on the physical fitness of children by including data one year after restrictions were lifted. We found that recovery of most physical fitness components is incomplete, with values remaining lower in 2022 compared to 2019. This lack of immediate rebound suggests that the negative effects of the pandemic on physical fitness may linger if no countermeasures are introduced. Still, a short follow-up period of our study precludes extrapolation of future trends, and fitness surveillance systems should be leveraged to identify trajectories of fitness across population groups over the coming years and monitor to what extent children have regained their pre-pandemic fitness levels. We found that post-pandemic fitness catch-up was much less evident for health-related than for skill-related fitness. Given the well-known long-term consequences of low physical fitness in adolescence on both immediate and future health, as well as on longevity,[1] this could present a large public health problem in the coming years. This highlights the importance of promoting physical activity in children, particularly in the context of the post-pandemic period.

Physical fitness levels are partly genetically determined but are also influenced by a variety of environmental factors beyond just the COVID-19 pandemic and associated restrictions. For example, changes in physical activity patterns and dietary habits, as well as changes in sleep patterns, can also impact physical fitness levels.[12] A significant impact on physical fitness that is related to the COVID-19 restrictions, with decreases observed in all components of physical fitness between 2019 and 2020 might be due to several reasons. During the pandemic, many opportunities for physical activity were limited or unavailable.[12,17,18] The impact of COVID-19 was furthermore exacerbated by the negative impact of restrictions on physical fitness likely due to reduced opportunities for sports participation, as well as increased sedentary behaviour due to remote learning, and decreased social interactions.[8,18,48] It should be pointed out that during the pandemic Slovenia had a lot of movement initiatives, but obviously, through their implementation children never managed to reach the levels that they normally have in school and sports clubs. A recent study on Slovenian children has shown that during the lockdown children spent ~46 min per day less time in moderate-to-vigorous physical activity and had consistently less sleep.[12] However, it is important to note that the impact of the restrictions on physical fitness varied depending on the weight status of the children before the pandemic. The COVID pandemic has reduced the weight-based inequalities in physical fitness but at the expense of the largest group–children with normal weight–who have deteriorated their physical fitness, and come closer to the groups with overweight and obesity. The impact of COVID-19 measures on children's physical activity was global, but Slovenia

might have been more affected by the COVID-19 measures (especially school closures) than most other countries as they do not have so many physical activity initiatives implemented through the school system. Our recent analysis of a scaled-up physical activity intervention showed that the Slovenian advantage in terms of maintaining and improving the physical fitness of children lies in the educational setting,[49] and demonstrates that Slovenia has the knowledge and experience needed to combat the current situation. Results of this study were already presented in front of the Slovenian parliament which decided to prepare the grounds for the re-launch of a nationwide physical activity programme in schools (i.e., *Healthy Lifestyle Intervention*), which still did not happen.

Promoting physical activity and healthy habits in children can be challenging, but there are a variety of strategies that can be used to encourage children to engage in physical activity and maintain healthy lifestyles. These include promoting active transportation, such as walking or biking to school,[50] providing opportunities for structured physical activity during the school day,[49,51] and providing access to safe and affordable recreational facilities.[52] Additionally, educating parents and caregivers about the importance of physical activity and healthy lifestyles can help to promote healthy habits in children from an early age.[53–55] Due to universal coverage, schools are considered an ideal setting for introducing lifestyle changes in children. School-based physical activity interventions have been shown to be effective,[56,57] but other settings that are less susceptible to disruptions when unprecedented situations occur should also be considered. Whole school-approaches such as comprehensive school-based physical activity programmes are considered the gold standard for increasing physical activity in youth.[58] These programmes are multi-component and include high-quality physical education, physical activity during school hours (e.g., active lunch and recess breaks, and classroom physical activity breaks), physical activity before and after school (e.g., active transportation to school and extracurricular activities), staff involvement, and family and community engagement. In addition to school setting, future policy action should aim to build supportive social and built environments conducive to a range of physical activity behaviours.[59]

There are several strengths of our study. First, the longitudinal design of the study, with physical fitness assessed yearly over four time points, allowed for comprehensive and robust conclusions about the short- and mid-term impact of COVID-19 restrictions on physical fitness in children. All studied outcomes were objectively measured by trained personnel each year, which increased the reliability of the data. We included a large sample of 41,330 children from all regions of Slovenia, which enhances the generalizability of the findings. The inclusion of different weight status groups adds to the strengths of the study because physical fitness changes were assessed in children with normal weight, overweight, and obesity before and after the pandemic, which provided insight into how the pandemic has impacted weight-based inequalities in physical fitness. The focus of the study on children is also important because physical fitness during childhood is related to physical, mental, and cognitive health, and is a strong predictor of distant health outcomes.[2,5,56,60,61] Overall, these strengths increase the reliability and validity of the study's findings and provide important insights into the impact of COVID-19 restrictions on physical fitness in children.

It is also necessary to note several limitations of this study. Firstly, we adjusted the analyses for age, but did not collect data on several other characteristics that could have confounded weight-based inequalities in fitness, such as pubertal development or socioeconomic status. Still, we have attempted to address maturation by adjusting the models for height centile across time. Similarly, we tried to eliminate the effect of socioeconomic status by adjusting the models for school-level as an area-level socioeconomic indicator. Nonetheless, as individual and area-level socioeconomic indicators agree only moderately,[62] some residual confounding is likely. Next, we combined all ages for the analyses and did not focus on the effect of age group on the observed patterns of change in physical fitness. For example, younger children may have had more difficulty adapting to the changes in their PA levels during the pandemic, whereas older children may have been more able to find alternative ways to stay active. Finally, we cannot deduce the reasons for the observed changes in physical fitness as we have no data on potential mediators, such as concurrent changes in diet, sleep, sedentary behaviour, or psychological factors related to the pandemic (e.g., stress, anxiety, or depression).

Conclusion

We provided a comprehensive analysis of the temporal trends of different physical fitness components among children of diverse weight status during and after the COVID-19 pandemic. We have identified diverging trends in physical fitness in the aftermath of COVID-19 across weight groups, sex, and fitness components. As we observed incomplete recovery from the decrease in physical fitness witnessed during the restriction measures in most groups of children, no targeting is advisable at this time and population-based initiatives are warranted instead. Our findings that span a comprehensive set of fitness attributes provide directions for tailoring urgently needed physical activity policies, with a special reference to some of the most vulnerable groups of children (i.e., girls with overweight or obesity). On the other hand, by delineating the immediate effects of pandemic-related measures on a large set of fitness domains, our results point to the

dimensions of fitness that have been affected most severely during the pandemics across different groups. This can help policymakers prioritize and better tailor policies in times of future public health crises in order to mitigate these negative side effects of essential containment measures.

Future studies are needed to understand long-term trends in the physical fitness of children and to verify if physical fitness trajectories have regained pre-pandemic levels. These studies should examine trends in the physical fitness of children divided into different weight and fitness status groups, while also considering other factors that affect growth and development such as maturation tempo or socioeconomic status.

Contributors

With the intention to recognize the individual contributions of authors, the CRediT (Contributor Roles Taxonomy) framework and the International Committee of Medical Journal Editors (ICMJE) Recommendations are followed. Antonio Martinko: Conceptualization, Methodology, Software, Formal analysis, Data Curation, Writing–Original Draft, Writing–Review & Editing, Visualization; Maroje Sorić: Conceptualization, Methodology, Writing–Original Draft, Writing–Review & Editing, Supervision, Project administration; Gregor Jurak: Conceptualization, Writing–Review & Editing; Gregor Starc: Conceptualization, Data Curation, Writing–Review & Editing.

Data sharing statement

Individual participant data after de-identification and analytic code that underlie the results reported in this article (text, tables, figures, and appendices) will be available (including data dictionaries). Data used in this study are available to researchers who provide a methodologically sound proposal to achieve the aims in the approved proposal. The data will be available beginning 3 months and ending 5 years following article publication. Proposals should be directed to antonio.martinko@kif.unizg.hr; to gain access, data requestors will need to sign a data access agreement. Data will be made available beginning 3 months and ending 5 years following article publication at a third-party website (https://osf.io/).

Declaration of interests

No conflicts of interest are declared.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanepe.2023.100748.

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