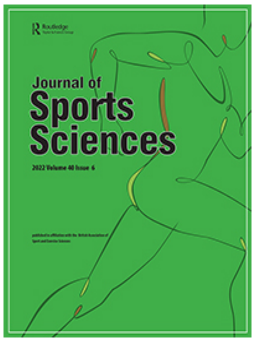

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Changes in children's physical fitness, BMI and health-related quality of life after the first 2020 COVID-19 lockdown in England: A longitudinal study

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ABSTRACT

We aimed to assess one-year changes in physical fitness, health-related quality of life (HRQoL) and body mass index (BMI), encompassing the 2020 COVID-19 UK lockdowns. Data were collected (October 2019, November 2020) from 178 8–10–year-olds in Newcastle-upon-Tyne, England, 85% from England's most deprived quintile. Twenty-metre shuttle run test performance (20mSRT), handgrip strength (HGS), standing broad jump (SBJ), sit-and-reach, height, body mass, HRQoL (Kidscreen-27 questionnaire) and sports club participation were measured. BMI z-scores and overweight/obesity were calculated (≥85th centile). Paired t-tests and linear regression assessed change, adjusting for baseline BMI. Significant ($p<0.001$) changes were observed: increases in mean BMI ($+1.5kg{\cdot}m^{-2}$), overweight/obesity (33% to 47%), SBJ (+6.8cm) and HGS (+1.5kg); decreases in 20mSRT performance (−3 shuttles), sit-and-reach (−1.8cm). More children at follow-up were categorized "very low" for 20mSRT performance (35% baseline v 51%). Increased BMI z-score was associated with decreased "Physical Wellbeing" HRQoL. Follow-up sports club participation was associated with better 20mSRT performance ($p=0.032$), and "Autonomy & Parents" ($p=0.011$), "Social Support & Peers" ($p=0.038$) HRQoL. Children's 20mSRT performance and BMI changed adversely over one year; national lockdowns potentially made negative contributions. Physical fitness, physical activity and sports programmes should be part of children's physical and mental recovery from the pandemic.

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KEYWORDS
Aerobic; child health; socioeconomic status; public health

Introduction

Coronavirus disease (COVID-19) is an infectious disease (World Health Organisation, 2021), first reported by the Wuhan Municipal Health Commission, China, in December 2019 (World Health Organization, 2021) and later confirmed as a pandemic by the World Health Organisation in March 2020 (World Health Organisation, 2020). The pandemic continues to have global implications; as of 7 January 2022 there have been 298.9 million confirmed cases and 5.47 million deaths worldwide (World Health Organisation. WHO Coronavirus, 2021). The associated infection control measures such as isolation and social distancing may have had a unique impact on children's physical and mental health (Singh et al., 2020). For example, schools in England closed to most pupils from March to September 2020 (Institute for Government, 2021), with outdoor exercise limited to one hour/day from March to May, and outdoor playgrounds and sports clubs closed from March to July 2020 (Sport England, 2021). Initial reports suggested the lockdown would have a detrimental effect on physical activity and fitness levels, thereby potentially increasing obesity (Yang et al., 2020). It was also demonstrated that some children and young people's mental wellbeing suffered with lockdown (Shum et al., 2021; Millar et al., 2020), but others reported that levels of resilience in this population were high (Department for Education, 2020). A social gradient in both activity levels and mental wellbeing was expected or reported (Sallis et al., 2020; Millar et al., 2020), with those from a less affluent background less likely or able to be active, and to suffer more from mental ill-health, thus widening existing inequalities (Bambra et al., 2020).

Physical fitness levels in children are important independent predictors of health outcomes, including cardiovascular and skeletal health, adiposity, and mental wellbeing (Ortega et al., 2008). Health-related quality of life (HRQoL) is a complex, subjective view of physical, social, and emotional wellbeing, related to an individual's health state (Seid et al., 2000). Evidence is emerging that higher physical fitness in childhood is associated with better HRQoL (e.g., in Spanish 8–11-year-olds (Morales et al., 2013), American 9–11-year-olds (Gu et al., 2016), and Swiss 6-8-year-olds (Gerber et al., 2017)), but more evidence is required, and particularly from longitudinal studies (Lang et al., 2018).

As many research and surveillance programmes were cancelled or reduced globally (e.g., England's National Child Measurement Programme (Public Health England, 2020a)), few empirical datasets exploring the potential impact that lockdowns had on young people's BMI or physical fitness are available, and the results are mixed. One study in 89 Spanish 12–14 year-olds found no significant

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change in group-level aerobic fitness (measured indirectly via 20 m shuttle run test (20mSRT)), (López-Bueno et al., 2021) unlike data from both Slovenia (11 measures including 600 m endurance run from n = 20,000 6–14-year-olds (Jurak et al., 2021; SLOfit, 2021)) and the United States (n = 284, 8–14-year-olds, 20mSRT, push-ups, sit-ups (Wahl-Alexander & Camic, 2021)), where a reduction in both strength (e.g., −35.6% for push-ups) and aerobic fitness (−26.7%) was observed. Currently, the impact of the COVID-19 pandemic on English children's physical fitness, BMI and HRQoL is unclear. This is compounded by a lack of longitudinal physical fitness data of UK children (Mann et al., 2020). We have previously described the physical fitness levels of children in North East England (Weston et al., 2019), and the associations with HRQoL (Basterfield et al., 2021). In the latter, 20mSRT performance was significantly associated with children's subjective physical wellbeing. Sports participation was also linked with other domains of HRQoL; however, there is a dearth of information on the longitudinal associations between physical fitness and HRQoL, particularly in children. As the COVID-19 lockdowns had the potential to detrimentally impact physical fitness, body mass index (BMI) and HRQoL, particularly to those in the most deprived areas of England, the primary aim of our study was to assess changes in children's physical fitness, BMI and HRQoL over a 12-month period, encompassing the first 2020 UK COVID-19 lockdown and school closure period. Our secondary aim was to explore the associations between the variables. We hypothesised that all components of physical fitness and HRQoL would decrease, and BMI increase, from baseline.

Methods

Participants

Ethical approval was granted by Newcastle University Faculty of Medical Sciences Ethics Committee (1614/7165/2018). Recruitment of the school was undertaken by the Newcastle United Foundation, an independent charitable organization in Newcastle upon Tyne. Participants were children in Year 4 and 5 at baseline (ages 8–10, n = 178) of one primary school in Newcastle upon Tyne, North East England, which was part of a larger cross-sectional study (see Basterfield et al. (2021) for full details), located in an area in the 15% most deprived in England. Individual-level index of multiple deprivation (IMD) data were obtained using home postcode and the freely available IMD data (Ministry of Housing Communities & Local Government, 2019).

The school head teacher gave written consent for the school's participation. Parents were sent an information leaflet with full study details and given the option of withdrawing their child from the study. Children were asked for their own written or verbal assent prior to taking part. There were no exclusion criteria. Data collection was completed in October 2019 (baseline) and 10 November–1 December 2020 (follow-up, England national lockdown 2 started on 5 November 2020; "stay at home" orders, but schools were open. School sports clubs had restarted with reduced numbers; outside-school sports had just been suspended). At both baseline and follow-up, no children were enrolled in additional interventions and/or programmes, which aimed to increase their physical activity and/or physical fitness levels. Further ethical approval was sought prior to follow-up, due to the increased risk posed by the pandemic; extra risk mitigation procedures were introduced (researchers wore face masks, enhanced cleaning of equipment between children, smaller group sizes, physical distancing where possible and increased room ventilation), and local and national guidance for COVID-19 infection control was followed (Public Health England, 2020b).

Anthropometry

Height was measured twice to the nearest 0.1 cm (Leicester height measure, SECA Ltd, Birmingham, UK) and body mass twice to the nearest 0.1 kg (Shekel H151-7, Shekel Scales Ltd, Israel) with children barefoot in light indoor clothing. Mean values were used for analysis. BMI ($kg \cdot m^{-2}$) and age- and sex-specific BMI z-scores relative to UK 1990 reference data (Cole et al., 1995) were calculated using the LMS Growth excel add-in. Population-sensitive cut-offs categorized children as either "underweight" (≤2nd centile or below), "healthy weight" (>2nd <85th centile) "overweight" (≥85th <95th centile) "obese" (≥95th <99.6th centile) or "severely obese" (≥99.6th centile and above).

Physical fitness components

The Eurofit testing battery (EUROFIT, 1988) was used, as described previously (Basterfield et al., 2021). Measures most closely associated with health outcomes (Ortega et al., 2008) were chosen: Aerobic fitness was indirectly assessed via 20mSRT performance using the British National Coaching Foundation protocol (Ramsbottom et al., 1988). Total number of completed shuttles was used in analysis. Handgrip strength (HGS) was measured using a digital hand dynamometer (Grip-D, TKK 5401, Takei, Tokyo, Japan). Dominant hand was recorded. Measurements were completed for both hands twice to 0.1 kg, with elbow flexion to 90° permitted (Cohen et al., 2010). Maximum score was used in analysis. Lower body strength was estimated via standing broad jump (SBJ). Three practices were followed by three measured attempts to the nearest cm. Maximum distance (cm) was used in the analysis. Sit-and-reach (SR) performance was measured using a steel sit-and-reach box. Three practices were followed by three measured attempts to the nearest 0.5 cm. The maximum reach distance (cm) was used in the analysis.

Health-related quality of life questionnaire

Kidscreen-27 (Ravens-Sieberer et al., 2007) assesses subjective health and wellbeing in children and adolescents and was developed for, and validated in, children and adolescents aged 8–18 years (Ravens-Sieberer et al., 2006). It has 27 items measuring five dimensions: Physical Wellbeing; Psychological Wellbeing, Parent Relations & Autonomy, Social Support & Peers; School Environment. Within each dimension, item scores were summed and transformed to T-scores with a mean ≈ 50 and SD ≈10. Higher scores indicated higher HRQoL. Responses were considered “low” if they were less than the mean-0.5*SD of the reference population (Ravens-Sieberer et al., 2006), with the expected proportion of “low” HRQoL 31% of the population (Ravens-Sieberer et al., 2006).

Sports club participation

Sports club participation was explored through the Leisure Time Physical Activity Survey (Burgess et al., 2006). Here, children provided details on whether they attended sports clubs at school and outside-school (i.e., in their leisure time), then type, weekly frequency and duration of club. Total time spent in sports clubs per week was calculated. Children completed the questionnaire by themselves if they were able to comprehend the questions or as a class with the teacher reading each question.

Statistical analysis

SPSS v.26 (IBM Corp.) was used for analysis. Comparisons with published International and European reference data for each physical fitness component were completed, except SR as the protocol varied substantially from ours (GR Tomkinson et al., 2018; G Tomkinson et al., 2017). For each physical fitness component, an age- and sex-specific quintile framework using the following centiles was adopted: <20th centile “very low”; ≥20th <40th centile “low”; ≥40th <60th centile “moderate”; ≥60th <80th centile “high”; ≥80th centile “very high”. The exact scores corresponding to each quintile are available from De Miguel-Etayo et al., 2014 (Miguel-Etayo P et al., 2014), Tomkinson et al., 2017 and 2018 (Tomkinson et al., 2018; Tomkinson et al., 2017). “Very low” is classed as “unfit” (Tomkinson et al., 2018).

Difference in variables from baseline to follow-up were assessed with Paired T-tests, which require that the distribution of the difference between the pairs is normally distributed, not the distribution at baseline and follow-up. For variables that did not conform to this requirement, the Related Samples Wilcoxon Signed Ranks test was used. Missing data were not interpolated. Change variables were created by subtracting the baseline value from the follow-up value. Effect sizes (Cohen’s *d*) point estimate and 95% Confidence Intervals were calculated. Associations between outcome variables and potential covariates (sex, IMD and age) were assessed individually with ANOVAs. IMD was not associated with any other variable so not included in further analyses.

Associations between variables were tested using Pearson’s correlation and linear regression. There were four separate sets of regression analyses:

1) associations of change in BMI with change in fitness. Independent variables: change-BMI z-score, baseline BMI z-score, sex and baseline age included together (single block forced entry). Dependent variables: change in each fitness variable (tested individually).

2) associations between change in HRQoL with change in BMI and fitness. Independent variables: change in BMI z-score, baseline BMI z-score, baseline age and sex (single block forced entry) and change in each fitness variable (forward stepwise). Dependent variables: change in each HRQoL domain (tested individually).

3) associations between time spent in sports clubs and fitness variables. Independent variable: time spent in sports clubs (min · wk^{-1}) at follow-up, plus baseline shuttles and follow-up BMI z-score as covariates. Dependent variables: follow-up fitness variables (tested individually).

4) associations between time in sports clubs and HRQoL domains. Independent variables: time spent in sports clubs (min · wk^{-1}) at follow-up, plus follow-up BMI z-score as covariate. Dependent variables: follow-up HRQoL domains (tested individually). Three and four were also completed using change variables. Adjusted R^2, B coefficient and 95% Confidence Intervals (95% CI) were calculated.

Categorical variables were tested using Chi^2. Significance was set at $p < 0.05$.

Results

Participants

Baseline data were collected from 178 children, 53.4% male and 94% from the White ethnic majority, 3% Mixed Race, 2% Asian, 1% Black and other ethnic groups. Numbers taking part at follow-up varied by measurement, depending on absences or refusal (one parent withdrew their child from the study; three children had left the school; some children refused the weight measurement; children were self-isolating); individual n are given for each variable. At baseline, 85.1% of the children lived in the most deprived quintile as assessed by IMD, 5.7% in the 2nd, 8.6% in the 3rd, 0% in the 4th and 0.6% in the least deprived.

Changes in anthropometry and physical fitness components

Baseline and follow-up variables are in Table 1. There were no differences in any fitness change variable between sexes, so the group was kept whole for assessing change over time. SBJ and HGS both increased significantly ($p < 0.001$). However, the total number of shuttles run decreased from mean 23.4 to 20.6 ($p < 0.001$). SR distance also decreased significantly from 15.3 to 13.5 cm ($p < 0.001$). The quintile analysis showed significant movement between the categories (“very low” to “very high”) for each fitness variable (Chi^2 $p < 0.001$ for all); more children were classed as “unfit” (very low) for 20mSRT (35% baseline v 51% follow-up), whilst fewer children were in the “very low” category for HGS (25% baseline v. 20% follow-up). SBJ results were similar for “very low” (31% baseline v 32% follow-up) but was the only variable to increase in the “very high” category (11% baseline to 16% follow-up). BMI and BMI z-score also increased significantly from baseline (Table 1, $p < 0.001$). BMI increased by 1.5 kg · m^{-2}, an average of 6.3 kg body mass and 6.8 cm height increase. Baseline mean BMI z-score was 0.70 for the 8–9y children and 0.75 for the 9–10y children. At follow-up that was 0.98 for the 9–10y children and 1.01 for the 10–11y children. There was no sex difference in BMI or BMI z-score.

Table 1. Changes in anthropometry and physical fitness variables from baseline to follow-up (means, standard deviation (SD) and 95% confidence intervals (95% CI)).

	Baseline		Follow-up		Difference		Effect size (Cohen's *d;* 95%CI)
Variable (n)	Mean	SD	Mean	SD	Mean (SD; 95% CI)	p	
Anthropometry							
Age (y) (163)	9.1	0.6	10.2	0.5	1.1 (0.03; 1.1,1.1)	<0.001	-
BMI (kg · m^{-2}) (146)	18.3	3.3	19.8	4.0	1.5 (1.5; 1.2,1.7)	<0.001	0.99; 0.79,1.19
BMI z-score* (146)	0.71	1.19	0.95	1.22	0.25 (0.47; 0.17,0.32)	<0.001	0.52; 0.35,0.69
Physical fitness							
20mSRT (total shuttles run) (141)	23	13.6	21	12.6	−3$^{\#}$ (9.1; −4.3,-1.3)	<0.001	−0.30; −0.47,-0.13
Standing Broad Jump (cm) (149)	122	23	129	24	6.8 (13.1; 4.7,9.0)	<0.001	0.52; 0.35,0.69
Handgrip strength (right hand, kg) (146)	13.2	3.1	14.7	3.3	1.5 (2.2; 1.1,1.8)	<0.001	0.66; 0.48,0.84
Handgrip strength (left hand, kg) (144)	13.1	3.0	14.4	3.1	1.3 (1.9; 1.0,1.6)	<0.001	0.67; 0.49,0.85
Sit-and-reach (cm) (148)	15.3	7.7	13.5	7.9	−1.8 (3.6; −2.4,-1.2)	<0.001	−0.50; −0.67,-0.33
Kidscreen-27 domains (T score)**							
Physical Wellbeing (137)	52.2	10.8	50.6	9.7	−1.6 (10.7; −3.4,0.2)	0.080	−0.15; −0.32,0.02
Psychological Wellbeing (138)	50.3	10.6	50.3	10.9	0.04 (10.8; −1.8,1.9)	0.965	0.00; −0.16,0.17
Parents & Autonomy (136)	49.9	10.4	51.3	10.5	1.4 (11.2; −0.4,3.3)	0.132	0.13; −0.04,0.30
Social Support & Peers (141)	51.6	11.0	53.7	10.4	2.0 (14.1; −0.4,4.3)	0.099	0.14; −0.03,0.31
School Environment (139)	52.0	10.8	52.0	9.9	0.07 (12.3; −2.0,2.1)	0.950	0.01; −0.16,0.17

*Assessed against UK90 data (Cole et al. 1990) . # Not −2 due to rounding. BMI – body mass index kg · m^{-2}, 20mSRT = 20m shuttle run test. **Within each dimension, item scores were summed and transformed to T-scores with a mean ≈ 50 and SD ≈10. Higher scores indicated higher HRQoL.
Cole TJ, Freeman J, Preece M. Body mass index reference curves for the UK, 1990. Arch Dis Child. 1995;73 (World Health Organisation, 2021):25–9.

Change in HRQoL

Baseline HRQoL variables were significantly positively correlated with each other (Pearson's r = 0.229–0.577), as were follow-up HRQoL domains (Pearson's r = 0.169–0.497) except Physical Wellbeing with School Environment (r = 0.124, p = 0.133 at baseline and r = −0.130, p = 0.091 at follow-up). Longitudinal correlations between baseline and follow-up HRQoL variables were more mixed; baseline Physical Wellbeing was correlated only with follow-up Physical Wellbeing, and baseline School Environment was not correlated with any follow-up HRQoL domain. However, 10/15 of the remaining associations were significantly positively correlated. Mean HRQoL did not change significantly for any of the domains from baseline to follow-up (Table 1) although there was considerable variability in how individual children changed. The only sex difference in HRQoL change variables was for change in Psychological Wellbeing, boys increased by 1.7, while girls decreased by 2.0 points (p = 0.04). Older children reported a greater increase in Physical Wellbeing (p = 0.004) and School Environment (p = 0.001) than younger children. When the proportions of "low" HRQoL were calculated, there were negative changes from baseline to follow-up for Physical Wellbeing (from 34.0% to 41.0% of the sample), but positive changes for all other domains (Psychological Wellbeing 46.2% to 39.7%, Parents & Autonomy 35.9% to 30.1%, Social Support & Peers 29.7% to 23.4%, School Environment 36.5% to 33.3%). However, the proportion of children who reported "low" for all five domains increased from 24.5% at baseline to 30.5% at follow-up, and 9% of children reported "low" for all domains at both timepoints. There was no sex difference in the total number of domains reported as "low" (p = 0.104).

Change in overweight levels

A significant number of children moved up a weight category (Table 2), with 47% obese or severely obese at follow-up compared with 33% at baseline (Wilcoxon Signed-Ranks test; 110 children stayed in same weight category, 33 moved up a weight category, 3 moved down (Z – 4.867 P < 0.001)).

Change against change

Change in BMI z-score was associated with change in 20mSRT and change in SBJ: Children whose BMI z-score increased the most over one year showed the greatest decrease in 20mSRT and the greatest decrease in SBJ, after controlling for baseline BMI z-score (Table 3). There was no association of change in BMI z-score with the other fitness change variables.

Table 2. Change in weight status from baseline to follow-up.

		Baseline categories of weight status*, n					
		Underweight	Healthy weight	Overweight	Obese	Severely obese	Total
Follow-up categories of weight status*, n	Underweight	-	-	-	-	-	-
	Healthy weight	2	76	-	-	-	78
	Overweight	-	15	9	2	-	26
	Obese	-	5	8	15	1	29
	Severely obese	-	-	-	3	10	13
Total		2	96	17	20	11	146

*Assessed against UK90 data (Cole et al., 1990) "underweight" (≤2nd centile or below), "healthy weight" (>2nd <85th centile) "overweight" (≥85th <95th centile) "obese" (≥95th <99.6th centile) or "severely obese" (≥99.6th centile and above). "-" indicates no children in this cell. Shaded cells indicate the number of individuals who have stayed in the same category.
Cole TJ, Freeman J, Preece M. Body mass index reference curves for the UK, 1990. Arch Dis Child. 1995;73 (World Health Organisation, 2021):25–9.

Change in BMI z-score was negatively associated with change in Physical Wellbeing (Table 4), i.e., children whose BMI z-score increased the most reported the greatest decrease in Physical Wellbeing. There was no association between change in HRQoL and change in 20mSRT, SBJ or HGS (Table 4). Change in SR was positively associated with Psychological Wellbeing.

Sports clubs

There was no significant decrease in mean time spent in sports clubs (baseline 231 min/wk v. 209 min/wk at follow-up, $p = 0.349$), although 87 children took part in a sports club at baseline, only 61 children participated in a sports club at both timepoints. 20mSRT performance at follow-up was significantly associated with the number of minutes spent in sports clubs at follow-up, even after accounting for both baseline shuttles and follow-up BMI z-score (adj. $R^2 = 0.60$, $p = 0.032$). Total time spent in sports clubs during lockdown showed small but significant positive associations with both Autonomy & Parents (adj. $R^2 = 0.06$, $p = 0.011$) and Social Support & Peers (adj. $R^2 = 0.038$, $p = 0.031$), independent of follow-up BMI z-score. There were no associations between change in time at sports club and any other change variable.

Discussion

This study aimed to provide the first empirical evidence from the UK on the changes in children's physical fitness, BMI and HRQoL that occurred during the UK national lockdown of 2020. Baseline data collection for this study was undertaken in October 2019, two months before COVID-19 had first been reported (World Health Organization, 2021), and five months before the first UK national lockdown when schools closed to most children for nearly six months (Institute for Government, 2021). The follow-up data collection took place during the second national lockdown (November 2020), when schools remained open.

Although small significant increases were observed in both SBJ and HGS, the reduction in 20mSRT performance, combined with the number of children classed as "unfit"

Table 3. Summary of linear regression models predicting change in fitness variables by change in anthropometry variables.

	Dependent variable: change in fitness variable Unstandardized B (95% CI)									
Independent variable	Change in total shuttles	p	Change in max jump distance (cm)	p	Change in right max handgrip (kg)	p	Change in left max handgrip (kg)	p	Change in max sit-and-reach (cm)	p
Constant	−11.46 (−36.38, 13.45)	0.364	22.63 (−9.23, 54.49)	0.162	−1.38 (−7.22, 4.45)	0.640	−0.76 (−6.10, 4.58)	0.779	−7.75 (−17.53, 2.02)-	0.119
Sex (male = 1, female = 2)	0.98 (−2.03, 3.99)	0.519	2.73 (−1.21, 6.67)	0.173	0.45 (−0.27, 1.16)	0.220	0.24 (−0.42, 0.89)	0.479	−0.07 (−1.27, 1.13)	0.909
Baseline age (y)	0.99 (−1.64, 3.62)	0.458	−1.70 (−5.08, 1.68)	0.321	0.22 (−0.40, 0.85)	0.477	0.19 (−0.38, 0.76)	0.507	0.67 (−0.37, 1.71)	0.203
Change in BMI z-score	−5.69 (−8.88, −2.50)	0.001	−8.37 (−12.51, −4.22)	<0.001	0.30 (−0.44, 1.05)	0.421	0.24 (−0.45, 0.93)	0.499	0.17 (−1.08, 1.42)	0.789
Baseline BMI z-score	−0.10 (−1.35, 1.16)	0.878	−3.2 (−4.84, −1.56)	<0.001	−0.01 (−0.31, 0.29)	0.963	−0.15 (−0.43, 0.13)	0.292	−0.15 (−0.65, 0.35)	0.554
Final model Adjusted R^2	6.8%		16.5%		−0.11%		−0.10%		−1.3%	

Table 4. Summary of linear regression models predicting change in health-related quality of life (HRQoL) by change in anthropometry and fitness variables.

	Dependent variable: change HRQoL domain Unstandardized B (95% CI)									
Independent variable	Change in Physical Wellbeing	p	Change in Psychological Wellbeing	p	Change in Parents & Autonomy	p	Change in Social Support & Peers	p	Change in School Environment	p
Block 1: Anthropometry (forced entry)										
Constant	−40.95 (−71.34,-10.56)	0.009	10.59 (−23.00,44.17)	0.534	11.84 (−23.75,47.42)	0.511	−32.69 (−73.50,8.12)	0.115	−60.34 (−97.06,-23.62)	0.001
Sex[a]	−1.80 (−5.42,1.83)	0.328	−6.03 (−9.94,-2.12)	0.003	−3.73 (−7.96,0.51)	0.084	−0.57 (−5.42,4.72)	0.816	−3.75 (−8.09,0.60)	0.090
Baseline age (y)	4.53 (1.34,7.72)	0.006	0.01 (−3.50,3.5)	0.997	−0.68 (−4.40,3.04)	0.718	3.75 (−0.54,8.03)	0.086	7.08 (3.23,10.92)	<0.001
Baseline BMI z-score	2.45 (0.84,4.06)	0.003	0.37 (−1.35,2.09)	0.673	0.41 (−1.46,2.27)	0.667	2.63 (0.48,4.78)	0.017	1.09 (−0.83,3.01)	0.263
Change BMI z-score	−4.66 (−8.43,-0.89)	0.016	−3.38 (−7.47,0.71)	0.104	−0.69 (−5.35,3.98)	0.772	−2.21 (−7.30,2.89)	0.393	0.78 (−3.77,5.33)	0.734
Block 2: fitness[b] (forward stepwise)										
Change in sit-and -reach (cm)	-	-	0.70 (0.16,0.13)	0.012	-	-	-	-	-	-
Final model adjusted R^2	16.8%		10.4%[c]		−0.01%		5.4%		12.6%	

[a]Male = 1, female = 2; [b]only significant ($p < 0.05$) change fitness variables are put forward through the analysis, and thus presented; [c]Block 1 only Adjusted R^2 = 6%.

increasing to around 50% for 20mSRT, plus the increase in BMI z-score are cause for concern. At baseline, the difference in BMI z-score between the two-year groups was 0.05, and in the larger sample that took part in the baseline data collection (Basterfield et al., 2021) the difference between three consecutive year groups was 0.03. That should let us expect that the follow-up BMI z-score increase would again be around 0.03–0.05. However, we found increases of 0.28 in the 9–10 year-olds and 0.26 in the 10–11 year-olds. A recent study from children of a comparable age in the USA found similar increases (Weaver et al., 2021). With a mean age of 8.9y (SD2.1), the n = 182 samples showed yearly pre-pandemic BMI z-score increases of 0.03 (similar to our finding). However, the increase following the pandemic was 0.34 in the full sample (65% of children were of Black ethnicity) and 0.22 for the White children (our demographic is 94% White; Weaver et al., 2021), again similar to our results. In Austria, n = 764, 7–10-year-olds completed a six-minute-run test and had BMI measured in 2019 and 2020 (Jarnig et al., 2021). BMI z-score increased by 0.16 in one year post-lockdown (0.23 for boys and 0.09 for girls), whilst cardiorespiratory fitness decreased (Jarnig et al., 2021).

The relationship between young people's aerobic fitness and age is already extensively documented (Armstrong & Welsman, 1994). In boys, a near linear increase in peak oxygen uptake (VO_{2peak}) from the age of 8 to 16 years has been observed, with regression equations indicating that VO_{2peak} increases by ~150% over this time. In girls, a similar but less consistent trend has been observed, with VO_{2peak} increasing by ~80% from the age of 8 to 16 years (Armstong & Fawkner, 2007). For 20mSRT performance (an indirect assessment of aerobic fitness), European (Tomkinson et al., 2018) and International (Tomkinson et al., 2017) data at the 50th centile show increases from age 9 years to 11 years for boys' 20mSRT performance from 32 to 36 shuttles, SBJ 133.8 cm to 151.9 cm, HGS 15.3 kg to 19.0 kg, and for girls 20mSRT performance 26 to 28 shuttles, SBJ 12.9 cm to 140.0 cm, HGS 13.6 kg to 17.5 kg. Over a normal year therefore, it would be reasonable to expect improvements in our participants' aerobic and muscular fitness. Indeed, the mean difference in 20mSRT performance between the year groups in our children at baseline was +2 shuttles, so we could expect that the follow-up scores would also increase by a similar margin. In light of the COVID pandemic and associated restrictions; however, we hypothesised that there would be a reduction in all physical fitness components. This was true for 20mSRT performance as the number of shuttles completed significantly decreased by a mean −3 shuttles, and for SR distance decreased significantly from an average of 15.3 cm to 13.5 cm.

Given the importance of aerobic fitness in youth to favourable metabolic profiles later in life (Ortega et al., 2008) and combined with the accelerated increase in BMI, these findings are of great concern, with the potential to increase the risk of cardiovascular disease. Encouragingly, however, we observed a significant increase in both SBJ (from 122 cm to 129 cm, and despite the increase in BMI) and HGS (13.2 kg to 14.7 kg). These data are more in line with improvements expected during non-pandemic times, where increases in both aerobic fitness and muscular fitness are expected as children age (Tomkinson et al., 2018; Tomkinson et al., 2017). Collectively, our findings suggest that children's aerobic fitness (i.e., 20m SRT performance) may be more susceptible to decline over the lockdowns than muscular fitness components (i.e., SBJ and HGS). This may reflect changes in the children's movement behaviours during the pandemic and/or limits placed on their opportunities to be active. While speculative as we did not measure physical activity, this has begun to be explored by others (Paterson et al., 2021).

Other authors have reported post-lockdown physical fitness results. A nationwide fitness testing programme in Slovenia (Jurak et al., 2021) has produced preliminary results from the year 2020 on n = 20,000 6–14 year-olds indicating the largest decline in fitness levels (particularly the 600 m endurance run) in 30 years, when systematic testing began. That was after just a two-month isolation/lockdown period. A longitudinal study (2019–2020; Wahl-Alexander & Camic, 2021) from the United States with n = 264 8–14 year-olds found similar results to us, reporting significant increase in BMI (18.8 kg · m^{-2} at baseline v. 20.8 kg · m^{-2} at follow-up), and significant reductions in 20mSRT (31.4 laps at baseline v. 22.4 laps at follow-up) during a 12-month period encompassing their 11–15 week school closures. They also reported decreases in the number of push-ups and sit-ups, but currently there is no comparison for those, and these measures may be adversely affected by increased BMI (Thivel et al., 2016). An Austrian study of 7–10-year-olds (Jarnig et al., 2021) reported a significant post-lockdown reduction in 6-minute-run distances (917 m v. 815 m), with children who participated in sports clubs having higher cardiorespiratory fitness at all time points. Conversely, a study with n = 89 Spanish 12–14 year-olds (where a strict curfew was in place for 6 weeks, followed by a slow easing of some restrictions; López-Bueno et al., 2021) reported no overall change in cardiorespiratory fitness measured indirectly via 20mSRT (López-Bueno et al., 2021). A recent pre-COVID-19 English study reported a greater decrease in 20mSRT over one year in children from deprived communities compared to those from less deprived areas (Mann et al., 2020), which may be reflected in our results, as the children in our study lived in the 20% most deprived areas of England. Although a reduction in 20mSRT performance (Mann et al., 2020) and treadmill-walking VO_{2max} (Carrel et al., 2007) is seen over the summer vacation, measuring the children at the same time of year should have negated that particular impact in our study. A report from the Born in Bradford study (Bingham et al., 2021), based in a deprived northern English city, found a large reduction in the children classed as "sufficiently active" (i.e., doing 60 min/d moderate-to-vigorous intensity physical activity) during lockdown 1 compared with pre-pandemic. The reduction in 20mSRT performance observed by us and others may have been influenced by the enforced lockdown restricting the children's access to physically active play and sports.

We found no overall change in mean HRQoL domains from baseline to follow-up, and consequently no association of change in HRQoL with any of the change in fitness variables, although children whose BMI increased the most showed the greatest decrease in Physical Wellbeing. We found changes in the numbers of children reporting their HRQoL as "low": a greater proportion of children at follow-up reported low

Physical Wellbeing, which reflects their overall physical fitness results. Encouragingly, fewer children scored "low" on the other HRQoL domains, although the numbers were still greater than the expected 31% of the population (Ravens-Sieberer et al., 2006) for all except Parents & Autonomy and Social Support & Peers, and 9% of the children scored "low" in all domains at both timepoints. The lack of overall difference in mean HRQoL from baseline to follow-up could be due to several different factors. It may demonstrate the importance of school life, as testing during school-time (even during a lockdown) is more reflective of "normal" life. Children had been back at school for approximately six weeks, and anecdotally their teachers reported better than usual attendance and engagement with school in general, and children appeared happy to be back with their friends. This theory is supported by other research from during the pandemic which reported that children were struggling during the lockdown periods (Shum et al., 2021), with parents of 4–10 year-olds in the Co-SPACE study reporting more behavioural, emotional and attentional difficulties (as measured by the Strengths and Difficulties Questionnaire, SDQ (Goodman, 2001)). For example, the "behavioural difficulties" subdomain of the SDQ showed mean scores of 1.99 in March 2020, start of the lockdown (Shum et al., 2021). Scores then increased each month to a peak in June 2020 at 2.34, then gradually reduced with lockdown easing, to 1.74 in October. However, this improvement was lost as the next restrictions and lockdown progressed (January 2021 mean score 2.0, February 2.18), and then as the final lockdown ended in March 2021 scores dropped again (2.01; Shum et al., 2021). This pattern was mirrored in the other SDQ sub-domains, providing further evidence for avoiding measures that restrict children's usual routines. Further evidence comes from a study of n = 1,586 German children and adolescents, which found that the lockdowns and social distancing measures were a significant burden to them during 2020 (Ravens-Sieberer et al., 2021). Here, Ravens-Sieberer et al., (Ravens-Sieberer et al., 2021) reported that HRQoL decreased (15.3% reported low HRQoL before the pandemic compared with 40.2% during the pandemic), and parents reported a sharp increase in children's mental health problems (7.4% to 26.8% in 7–11 year-olds), while children from low socioeconomic backgrounds were affected more (Ravens-Sieberer et al., 2021).

The importance of continuing sporting activities through the pandemic was shown in our analyses by the positive association between time spent in sports clubs and both 20mSRT and SBJ, and with HRQoL. Although less than half of the children took part in a sports club at both time points, the significant associations with different HRQoL domains, 20mSRT and SBJ demonstrate the benefits of schools adapting to the distancing and "bubble" rules to continue offering sports clubs, as well as the considerable efforts of external sports providers once sport was permitted. A Sport England report (Sport England, 2021) into children's and adolescents' physical activity during April–July 2020 reported a significant drop in physical activity compared with 2019, particularly for boys, and unsurprisingly participation in team sports and swimming was particularly low (24.4% and 23.5% reduction, respectively; Sport England, 2021). The increase in walking (22.2%) and cycling (18.4%) mitigated the reduction somewhat, but the length of time that children were away from their usual activities impacted negatively on both their feelings of confidence and enjoyment in sport, as well as their resilience (Sport England, 2021). Although an older sample, a study of n = 473 Israeli 16–18 year-olds (Constantini et al., 2021) who participated in organized sport before the lockdown found that those who continued their participation online during the school closures (March–May 2020) (n = 333) reported better satisfaction with life and self-rated health, as well as feelings of being able to cope during the pandemic, and dealing with negative feelings compared with those who did not participate (Constantini et al., 2021). The authors describe the importance of the relationship the participants had with their coach in promoting feelings of resilience, as well as helping to achieve physical activity recommendations (Constantini et al., 2021). The reinstatement of sports clubs and quality Physical Education (García-Hermoso et al., 2020) may go some way to increasing both physical fitness and the associated mental wellbeing effects.

Our study has a relatively small sample size, as the 12-month follow-up of two other schools in the study was prevented by earlier lockdown restrictions. Most of the children were from a white ethnic background, from a deprived area, so we are unable to generalize to less deprived populations or other ethnicities. We are of course unable to attribute the detrimental changes in 20mSRT performance and BMI directly to the lockdowns, due to the lack of a comparator group. However, detailed data were collected by the same team of trained researchers, and COVID-19-safe protocols allowed for objective measures to be taken during a national lockdown, making this an important contribution to a very small pool of available empirical data.

Conclusions

Over a 12-month period encompassing the UK national lockdown and prolonged school closure period, children from a deprived area in North East England showed a concerning combination of reduced 20mSRT performance and increased BMI, which together may increase future risk of cardiovascular disease. Sport participation provided both physical and HRQoL benefits. Taken together, the importance of sport, physical activity and physical fitness for recovery from the COVID-19 lockdowns must be acknowledged (Richardson et al., 2021), with programmes to increase participation accelerated, and policies in place to support continued activity and involvement, both now and should future restrictions be required.

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Data availability statement

Data are available from the corresponding author upon request

Contributorship statement

Laura Basterfield: Conceptualization, Formal analysis, Investigation, Writing – Original Draft, Supervision. Naomi L. Burn: Investigation, Writing – Original Draft. Brook Galna: Formal analysis, Writing – Review & Editing. Guoda Karoblyte: Investigation, Formal analysis, Writing – Review & Editing. Hannah Batten: Investigation, Writing – Review & Editing. Louis Goffe: Investigation, Writing – Review & Editing. Matt Lawn: Investigation, Writing – Review & Editing. Kathryn L. Weston: Conceptualization, Writing – Original Draft, Supervision.

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