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Back to 'normal'? BMI, physical fitness and health-related quality of life of children from North East England before, during and after the COVID-19 lockdowns

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ABSTRACT

We assessed whether changes in children's body mass index (BMI), physical fitness and health-related quality of life observed post-2020 United Kingdom COVID-19 lockdown remained 12 and 18 months later. Twenty-metre shuttle run test (20mSRT), handgrip strength, standing broad jump, sit-and-reach, height, body mass, and health-related quality of life (Kidscreen27 questionnaire) were measured in 90 children (8–9 years) during October 2019 ("T0"), November 2020 ("T1"), November 2021 ("T2") and June 2022 ("T3"). Mixed-effects models showed age- and sex-normalised BMI increased from T0 (mean: 0.71) to T1 (0.97), remaining elevated at T2 (0.95) and T3 (0.89). Decreases in 20mSRT performance were observed from T0 (22.0) to T1 (19.3), then increased at T2 (23.5) and T3 (28.3). Standing broad jump and handgrip strength increased over time. The proportion of children with overweight/obesity increased from T0 (32%) to T3 (48%). Health-related quality of life decreased for "Physical Wellbeing" yet increased for "Autonomy & Parents". Our findings highlight that lockdowns may have had lasting implications for children's health, and the urgent need to reduce overweight and obesity in North East England. Improving health and fitness behaviours to maximise long-term health outcomes and build resilience to future emergencies and disruptions to health behaviours is also paramount.

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Introduction

The lockdowns implemented in 2020 and 2021 in response to the COVID-19 pandemic, reduced people's ability to move freely, as they were instructed to remain at home (Institute for Government, 2021). Adverse changes to physical health were reported, with an accelerated increase in children's body mass index (BMI) demonstrated in longitudinal studies. In the United States of America, age- and sex-normalised BMI (BMIz) scores increased by 0.34 (Brooks et al., 2021; Wahl-Alexander & Camic, 2021; Weaver et al., 2021), in Austria by 0.24 (Jarnig, Jaunig, et al., 2022), in China by 0.16 (Chang et al., 2021; Hu et al., 2021) and in the Republic of Korea by 0.40 (Gwag et al., 2021). In North East England, we reported detrimental changes in BMIz (+0.25) of 9–11 year-olds from 2019 to 2020, with concomitant increases in proportions of overweight/obesity (≥85th centile): increasing from 33% to 47% (Basterfield et al., 2022). We also observed a decrease in health-related quality of life (HRQoL) for children gaining the most weight (Basterfield et al., 2022). England's repeat cross-sectional study the National Child Measurement Programme (NCMP (NHS Digital 2021)), reported that the proportion of 10–11-year-old children with overweight/obesity increased from 35.2% to 40.9% between 2019/20 (pre-COVID) and 2020/21 (post-lockdowns) (NHS Digital 2021), but decreased to 37.8% in 2021/22 (NHS Digital, 2022).

Post-lockdown reductions in children's aerobic fitness have been reported in various cohorts including Slovenia (SLOfit), USA (Wahl-Alexander & Camic, 2021), Austria (Jarnig, Kerbl, et al., 2022), Germany (Wessely et al., 2022), Japan (Kidokoro et al., 2023), France (Chambonnière et al., 2021) and North East England (Basterfield et al., 2022). While some cross-sectional data from Germany showed no reduction (Eberhardt et al., 2022), this was attributed to previous efforts to increase aerobic fitness in this rural population. Global estimates suggest there was a reduction in children's overall daily physical activity of ~20% (Neville et al., 2022), and in the UK the reduction in opportunities to be physically active during the pandemic may have led to persistent reduced activity levels even once playgrounds and sports were available again (Salway et al., 2022). This lack of opportunity to be active over a prolonged period was extended once activities were available, as children

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were then unwilling to participate in activities they previously enjoyed, for reasons such as weight gain and feeling they were now unfit (Salway et al., 2022). This extended change in behaviour may have contributed to the observed reductions in physical fitness, as children were unable to maintain their previous levels of moderate-to-vigorous intensity physical activity, or other games and sports which contribute to cardiorespiratory and muscular fitness. However, recent data (2022) from a repeated cross-sectional study indicate that whilst moderate-vigorous intensity physical activity may be recovering to pre-pandemic levels, sedentary behaviours have remained elevated, so further investigation into the effects are needed (Jago et al., 2023).

While there is now a small pool of empirical studies (Basterfield et al., 2022; Chambonnière et al., 2021; Jarnig et al., 2021; SLOfit; Wahl-Alexander & Camic, 2021; Wessely et al., 2022) on the changes in BMI and physical fitness after the 2020 lockdowns, we are aware of only one cohort (Jarnig, Kerbl, et al., 2022) reporting whether these changes were sustained past the immediate phase once school closures ended and restrictions were eased. Here, an Austrian cohort measured yearly from September 2019 to 2021 observed an initial increase in BMI in 2020 which was sustained a year later, and a reduction in aerobic fitness unimproved a year later (Jarnig, Kerbl, et al., 2022). The aim of our study, therefore, was to assess whether changes in BMI, physical fitness and HRQoL observed between October 2019 and November 2020 after the 2020 school closures in England, remained 12 and 18 months later (i.e., November 2021 and June 2022, respectively).

Methods

Participants

Ethical approval for this study was granted by Newcastle University Faculty of Medical Sciences Ethics Committee (1614/7165/2018). Participants were children in English Year 4 at baseline (ages 8–9 years, $n = 90$) of a primary school in Newcastle upon Tyne, North East England, which was part of a larger longitudinal study (see (Basterfield et al., 2021)), 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. At each time point, 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, T0), November 2020 (T1), November 2021 (T2) and June 2022 (T3). The lockdown restrictions described in Table 1 were imposed in England during this time period (see Institute for Government, 2021 for a detailed timeline).

Further ethical approval was sought prior to follow-up, due to the increased risk posed by the pandemic, i.e., 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).

Data were collected as described in (Basterfield et al., 2021).

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.m^{-2}), and age- and sex-normalised BMIz relative to UK 1990 reference data (Cole et al., 1995) were calculated using the freely available LMS Growth excel add-in (Health for all Children, 2022) and presented as a z-score (i.e., standard deviations from the age- and sex-normative mean). UK 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) (Dinsdale et al., 2011).

Physical fitness components

The Eurofit testing battery (EUROFIT, 1988) was used (Basterfield et al., 2021). Measures most closely associated with health outcomes (Ortega et al., 2008) were chosen: Aerobic fitness was indirectly assessed via the 20mSRT protocol from the British National Coaching Foundation (Ramsbottom et al., 1988). Total number of completed shuttles was used in analysis. Handgrip strength 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), with the maximum score for the dominant hand used for analysis. Lower body strength was estimated via standing broad jump. Three practices were followed by three measured attempts and were measured to the nearest cm. Maximum jump distance (cm) was used for analysis. Sit-and-reach performance was measured using a steel sit-and-reach box. Three practice attempts were followed by three

Table 1. Timeline of COVID-19 restrictions in place during the study period.

England lockdown number	Dates	Restrictions
1	16th March-June/July 2020	Schools closed, followed by school holiday until end of August. Schools fully open to all pupils in September 2020.
2	5th November-2nd December 2020	"Stay at home" orders, but schools were open. School sports clubs had restarted with reduced numbers; outside-school sports had just been suspended.
3	6th January-8th March 2021	Schools closed.

measured attempts and were measured to the nearest 0.5 cm. The maximum reach distance (cm) was used in for 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; and 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.

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), followed by type, weekly frequency and duration of club. Total time spent in sports clubs per week was calculated. Children completed the questionnaire themselves if they were able to comprehend the questions, or as a class with the teacher reading each question. Sustained sports club participation was defined as the participation in at least one sport club at both T2 and T3 assessments.

Statistical analysis

Mixed effects models were fitted using the R statistics "lme4" package (Bates et al., 2015) to test whether anthropometric, fitness and HRQoL outcomes changed across the four assessments. For each outcome, sex and assessment were included as fixed effects and each child was modelled with a random intercept. Interactions between sex and assessment were modelled and only included in the final model if statistically significant. Preliminary analysis indicated that some outcomes had skewed distributions and the linear model residuals were heteroscedastic. As such, we tested whether lognormal and gamma generalised linear mixed models (with a log link) better fit continuous data, and negative binomial better fit count data. Where the models indicated that outcomes differed by assessment, estimated marginal means were used to compare between assessments using Tukey corrections for multiple comparisons. Next, linear regression examined whether change in BMIz was related to change in physical fitness since post-COVID-19 lockdown (calculated as T3–T1). Inputs included baseline sex, fitness outcomes at T1, overweight or obese status at T1, and change of fitness since COVID-19 lockdown (T3-T1). A full model was fitted with all possible interactions, and then non-significant fitness-based predictors (or interactions) were removed until a final model was reached. Model intercepts correspond to the mean values for boys at baseline (T0). Comparisons with published International and European reference data for each physical fitness component were completed, except sit-and-reach as the protocol varied substantially from ours (G. Tomkinson et al., 2017; G. R. Tomkinson et al., 2018). To contextualise our data against reference data, 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 (De Miguel-Etayo et al., 2014), Tomkinson et al. 2017 and 2018 (G. Tomkinson et al., 2017; G. R. Tomkinson et al., 2018). "very low" is classed as "unfit" (G. R. Tomkinson et al., 2018). McNemar paired-proportion tests were used to test if the proportion of children who had overweight or obesity (OWOB): i) changed over lockdown (T0 vs T1); ii) changed from just after lockdown to the final assessment (T1 vs T3); and whether it returned to pre-covid levels (T0 vs T3) by the final assessment. We repeated this analysis for the proportion of children who scored in the lower two quintiles (rated "low" or "very low") for physical fitness as defined using European and International references (as above), as well as the proportion of children who participated in sport clubs. For all analyses, a threshold of $p < 0.05$ was used to guide our interpretation. Uncertainty for estimates are presented as 95% confidence intervals ($CI_{95\%}$). Visualisations and analyses were performed in R (version 4.1.2, R Foundation for Statistical Computing). Estimated marginal mean differences between timepoints, with p values with Tukey adjustments for multiple comparisons are in Appendix 1.

Results

Participants

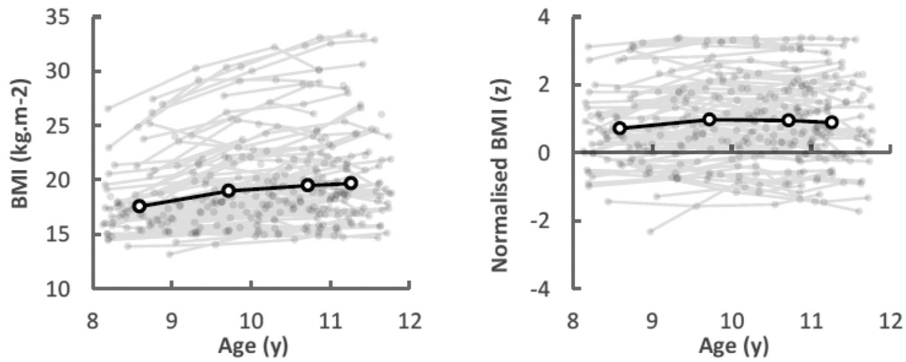
All 90 potential participants (50% female) took part at T0 in 2019; in 2020 three children left the school and the study ($n = 87$); in 2021 one child left and one joined ($n = 87$) and there were no changes in 2022. None of the children were withdrawn by their parent at any stage, therefore missing data are due to absence or refusal by the child.

At T0, ethnicity of participants was 91.1% White, 2.2% Asian, 1.1% Black, 4.4% Mixed Race and 1.1% of other ethnic groups, 85.6% were from the most deprived quintile, followed by 7.8% and 6.7% from the second- and third-most deprived quintiles.

Changes in body mass index

Body mass index (BMI) increased significantly from T0 to T1, and again from T1 to T2, with the greatest increase between T0 and T1 (encompassing lockdown 1) (Figure 1 and Appendix 2). BMI did not change between T2 and T3, and remained higher than T0. BMIz showed a different pattern: after an initial increase from T0 to T1, BMIz remained significantly higher than T0 at each subsequent assessment but did not increase any further. Neither BMI nor BMIz significantly differed between boys and girls.

The proportion of children with overweight or obesity was 32% (25/79) at T0, 46% (38/83) at T1, 44% (36/81) at T2 and 48% (39/82) at T3, with the proportion of children with overweight or obesity increased significantly from T0 to T1 (T1–T0 change: 12.2% ($CI_{95\%}$ 4.7%, 19.6%) $p = 0.003$) and remained high at T3 (T3–T0 change: 12.5% ($CI_{95\%}$ 2.4%, 22.6%) $p = 0.020$; T3–T1 difference: 1.3% ($CI_{95\%}$ −7.7%, 10.2%) $p = 0.782$). One child at T0 was underweight but no children were at any other



	BMI (kg.m^{-2}) Multiplicative estimates (CI$_{95\%}$)$^{p<.05}$ Gamma model, r^2= 10%	Normalised BMI (z) Additive estimates (CI$_{95\%}$)$^{p<.05}$ Gaussian model, r^2 = 0.7%
Intercept (T0, Male)	17.55 (16.23, 18.97)$^{T1, T2, T3}$	0.71 (0.35 – 1.07)$^{T1, T2, T3}$
T1	108% (106%, 110%)$^{T0, T2, T3}$	0.26 (0.14 – 0.38)^{T0}
T2	111% (110%, 113%)$^{T0, T1}$	0.24 (0.12 – 0.36)^{T0}
T3	112% (111%, 114%)$^{T0, T1}$	0.18 (0.06 – 0.29)^{T0}
Sex (Female)	103% (93%, 115%)	0.04 (-0.46 – 0.54)

Figure 1. Raw and age- and sex-normalised body mass index (BMI) for each child (light grey line) across each assessment (the cohort mean is indicated by open black circles). Superscript terms indicate significant differences between assessments ^{T} after Tukey's corrections for multiple comparisons, $p < 0.05$; intercepts indicate the cohort mean at baseline (T0) for a boy. BMI was modelled using a gamma distribution and so estimates are multiplicative – for example, mean BMI at T2 is 111% of T0 (17.55 kg.m^{-2} × 1.11 = 19.48 kg.m^{-2}). r^2 values indicate marginal r^2, namely, the variance explained by the fixed effects.

assessment. Whilst there were minimal refusals (2, plus 9 absent) for weight measurement at T0, these were found to not be at random; children with a lower BMI were more likely to have been assessed at each timepoint, therefore the T0 proportion of overweight may be an under-representation.

BMIz scores were highly correlated between assessments, ranging from $r = 0.860$ between T0 and T4, to $r > 0.900$ for every adjacent assessment ($p < 0.001$). This means that children with high BMIz scores were also likely to present with high BMIz scores at the final assessment.

Changes in physical fitness

Performance on the 20mSRT declined over the lockdown period (T0 vs T1) but returned to pre-covid levels by T2 before increasing to be significantly higher than T0 by T3 (Figure 2 and Appendix 2). Children jumped significantly further on the standing broad jump at T1 compared to T0, and further again at T3. Similarly, handgrip strength increased between each timepoint (Figure 2). Sit-and-reach decreased over lockdown to T1 but returned to baseline levels by T2 and remained stable at T3. Girls reached 7% further on the sit-and-reach test than boys, although achieved 28% fewer shuttles on the 20mSRT and 14% shorter distance on the standing broad jump.

Quintiles of physical fitness across each assessment, as defined by European and International references are shown in Figure 3.

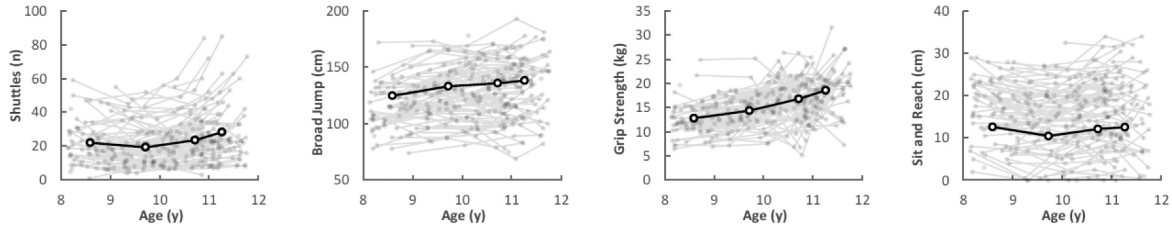
Changes in health-related quality of life

Patterns of change in HRQoL varied by domain (Figure 4 and Appendix 2). Physical Wellbeing worsened over time whilst scores on the Parents & Autonomy domain improved. HRQoL did not change consistently across the cohort for the Psychological Wellbeing or Social Support & Peers domains. Girls tended to score their HRQoL worse than boys for Physical, Psychological and Peers domains. In addition, we observed a sex by assessment interaction for the School domain, whereby the scores of girls declined over time but those of boys did not.

Sport club participation

The numbers of children taking part in school sports clubs was stable from T0 (30%) to T1 (32%), to T2 (32%) but reduced significantly at T3 (12%). Participation in outside-school sports clubs was highest at T0 (47%), then reduced at T1 (33%) and stayed stable at T2 (35%) and T3 (37%). The mean time spent in all sports clubs increased from 117 minutes at T0 to 165 minutes at T3. When combining school and outside sports clubs, 55% (42/76) participated in some form of sport club at T0 compared to 44% (39/89) at T1, 48% (41/85) at T2 and 46% (40/87) at T3. The proportion of children participating in a sport club was lower at T1 and T3 compared to before lockdown (T1–T0 change: −14.7% (−26.2%, −3.2%) $p = 0.016$; T3–T1

	Total Shuttles Run (n) Multiplicative estimates ($CI_{95\%}$)$^{p<.05}$ Negative Binomial model, r^2 = 12%	Broad Jump (cm) Additive estimates ($CI_{95\%}$)$^{p<.05}$ Gaussian model, r^2 = 13%	Hand grip strength (kg) Multiplicative estimates ($CI_{95\%}$)$^{p<.05}$ Gamma model, r^2 = 26%	Sit and Reach (cm) Additive estimates ($CI_{95\%}$)$^{p<.05}$ Gaussian model, r^2 = 19%



	Total Shuttles Run (n)	Broad Jump (cm)	Hand grip strength (kg)	Sit and Reach (cm)
Intercept (T0, Male)	21.97 (18.55, 26.02)$^{T1, T3}$	124.65 (117.96, 131.33)$^{T1, T2, T3}$	12.81 (11.72, 13.99)$^{T1, T2, T3}$	12.6 (10.54, 14.66)^{T1}
T1 (change from T0)	88% (80%, 96%)$^{T0, T2, T3}$	8.38 (5.55, 11.21)$^{T0, T3}$	112% (106%, 119%)$^{T0, T2, T3}$	-2.17 (-3.03, -1.31)$^{T0, T2, T3}$
T2 (change from T0)	107% (98%, 116%)$^{T1, T2}$	11.21 (8.38, 14.04)^{T0}	131% (123%, 139%)$^{T0, T1, T3}$	-0.47 (-1.32, 0.39)^{T1}
T3 (change from T0)	129% (119%, 140%)$^{T0, T1, T2}$	13.61 (10.77, 16.46)$^{T0, T1}$	145% (137%, 154%)$^{T0, T1, T2}$	-0.05 (-0.91, 0.81)^{T1}
Sex (Female)	72% (58%, 91%)^{Male}	-14.11 (-23.18, -5.05)^{Male}	95% (85%, 107%)	6.63 (3.81, 9.44)^{Male}

Figure 2. Fitness measures for each child (light grey line) across each assessment (the cohort mean is indicated by open black circles). Superscript terms indicate significant differences between assessments ^{T} after Tukey's corrections for multiple comparisons or sex ^{Male}, $p < 0.05$; Intercepts indicate the cohort mean at baseline (T0) for a boy. Estimates for Total Shuttles and grip strength are multiplicative – for example, mean grip strength at T2 is 134% of T0 (12.81 kg × 1.34 = 17.17 kg).

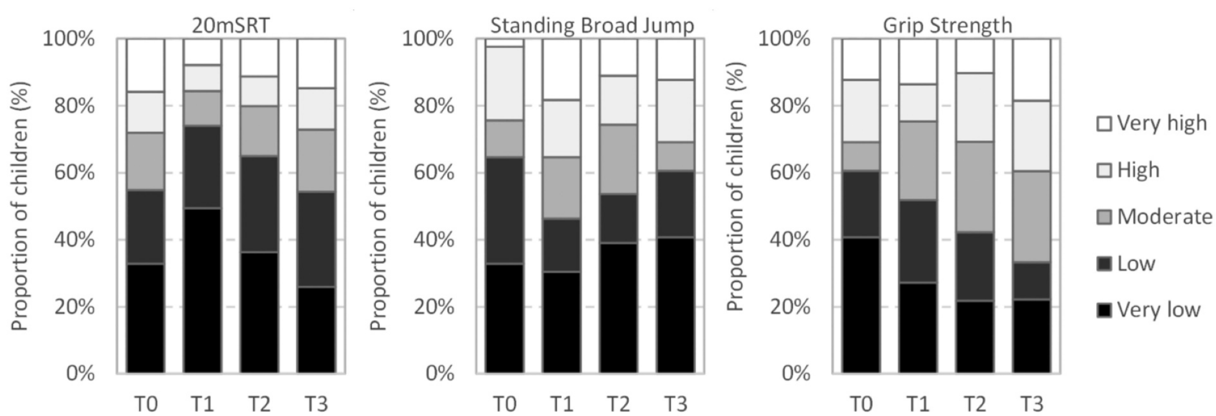
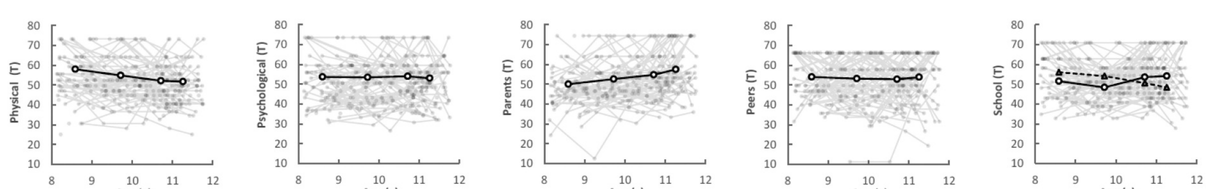


Figure 3. Quintiles for physical fitness showing proportion of children classed as "very high", "high", "moderate", "low" and "very low" fitness level. Data from T0 (October 2019) to T3 (June 2022).

	Physical Kidscreen (T) Additive estimates ($CI_{95\%}$)$^{p<.05}$ Gaussian model, r^2= 15.4%	Psychological Kidscreen (T) Additive estimates ($CI_{95\%}$)$^{p<.05}$ Gaussian model, r^2= 6.7%	Parents Kidscreen (T) Additive estimates ($CI_{95\%}$)$^{p<.05}$ Gaussian model, r^2= 9.1%	Peers Kidscreen (T) Additive estimates ($CI_{95\%}$)$^{p<.05}$ Gaussian model, r^2= 0.8%	School Kidscreen (T) Additive estimates ($CI_{95\%}$)$^{p<.05}$ Gaussian model, r^2= 4.3%



	Physical Kidscreen (T)	Psychological Kidscreen (T)	Parents Kidscreen (T)	Peers Kidscreen (T)	School Kidscreen (T): Boys	School Kidscreen (T): Girls
Intercept (T0, Male)	58.0 (55.3, 60.7)$^{T2, T3}$	53.7 (50.8, 56.6)	50.0 (47.0, 52.9)$^{T2, T3}$	54.1 (51.0, 57.1)	51.5 (48.1, 54.9)	56.1 (52.6, 59.5)
T1 (change from T0)	-3.12 (-5.50, -0.75)^{T3}	-0.22 (-3.03, 2.59)	2.65 (-0.08, 5.38)^{T3}	-0.82 (-4.07, 2.44)	-3.12 (-7.20, 0.96)	2.05 (-7.90, 3.79)
T2 (change from T0)	-5.80 (-8.23, -3.37)^{T0}	0.33 (-2.54, 3.20)	4.78 (2.00, 7.57)^{T0}	-1.22 (-4.54, 2.10)	2.10 (-2.10, 6.31)	-5.57 (-11.53, 0.39)
T3 (change from T0)	-6.25 (-8.65, -3.85)$^{T0, T1}$	-0.68 (-3.51, 2.16)	7.43 (4.68, 10.18)$^{T0, T1}$	-0.12 (-3.41, 3.16)	2.60 (-1.60, 6.79)	-7.68 (-13.57, -1.79)^{T*S}
Sex (Female)	-6.69 (-9.86, -3.53)^{Male}	-5.62 (-8.84, -2.40)^{Male}	-3.86 (-7.16, -0.56)^{Male}	-1.89 (-5.16, 1.38)		

Figure 4. Health-related quality of life (T scores) across five domains for each child (light grey line) across each assessment (the cohort mean is indicated by open black circles). Superscript terms indicate significant differences between assessments ^{T} after Tukey's corrections for multiple comparisons or sex ^{Male}, $p < 0.05$; Intercepts indicate the cohort mean at baseline (T0) for a boy.

difference: 1.2% (−8.2%, 10.6%) $p = 0.808$; T3–T0 change: −13.7% (−25.9%, −1.5%) $p = 0.033$).

Predicting change in BMIz since lockdown

Greater improvements in running (20mSRT) and standing broad jump from T1 to T3 was associated with the greatest reduction in BMIz (Table 2). Overweight/obesity status at T1 was not independently associated with change in BMIz, however, a significant interaction indicated that children with overweight or obesity at T1 experienced a greater reduction in BMIz associated with improvements in their running (20mSRT) than children who did not have overweight or obesity at T1. Baseline fitness, change in sit-and-reach and handgrip strength were not associated with change in BMIz. Consistent involvement in sports clubs at T2 and T3 did not predict change in BMIz ($p = 0.803$) or change in shuttle run performance ($p = 0.081$).

Secondary analysis

To help guide our interpretation, we performed two sets of analysis in addition to the planned statistics details in the methods. First, post hoc analysis showed that a higher 20mSRT score before lockdown (T0) was associated with a greater decline in 20mSRT from T0 to T1 ($r^2 = 22\%$, $p < 0.001$) and greater improvement from T1 to T3 ($r^2 = 19\%$, $p < 0.001$), and children whose shuttle run performance decreased most from T0 to T1 also improved most from T1 to T3 ($r^2 = 15\%$, $p < 0.001$) (Figure 5).

Second, additional analysis showed that sustained post-lockdown sport participation (reported playing in any sport club at T2 and T3) was associated with better 20mSRT at T3 ($r^2 = 14\%$, $p < 0.001$).

Discussion

This study aimed to explore whether the detrimental changes observed in children's BMI and aspects of physical fitness after the 2020 COVID-19 lockdowns remained 12 and 18 months later, as no studies to date have extended their follow-up into 2022. Pre-COVID (T0) data were collected in October 2019, and follow-up data collected in November 2020 (T1), November 2021 (T2) and June 2022 (T3). We found that the initial increases in BMIz observed after the first lockdown in 2020 remained in 2021 and had not reduced by June 2022. Conversely, 20mSRT scores reduced significantly after the first lockdown in 2020, but then recovered in 2021 and increased in 2022. Standing Broad Jump and Handgrip Strength increased over time, whilst sit-and-reach decreased then returned to baseline values. HRQoL generally decreased or stayed static, with a notable exception being an increase in the "Parents & Autonomy" domain.

Table 2. Predictors of change in normalised BMI (BMIz) from T1 to T3 (Change = T3 - T1), adjusted $r^2 = 36.3\%$.

Predictor	Additive estimates ($CI_{95\%}$) p $\Delta_{T3\text{-}T1}$ BMI z score per unit change of the predictor
Intercept	0.111 (−0.089, 0.312) $p = 0.272$
Overweight or obesity at T1 (Yes)	−0.075 (−0.356, 0.206) $p = 0.595$
$\Delta_{T3\text{-}T1}$ broad jump distance (cm)	−0.011 (−0.019, −0.003) $p = 0.009$*
$\Delta_{T3\text{-}T1}$ shuttles (n)	−0.040 (−0.060, −0.021) $p < 0.001$*
$\Delta_{T3\text{-}T1}$ shuttles (n) * overweight or obesity at T1 (Yes)	−0.032 (−0.055, −0.009) $p = 0.006$*

*$p < 0.05$.

Considering the rapid increase in BMIz of 0.26 units between T0 and T1, the lack of decline at T2 and T3 (12 and 18 months later) is worrying, especially as the population was already suffering from high levels of overweight and obesity at T0 (32%) when aged 8–9 years. This increased to 46% in 2020 (T1), and remained high at T3 in 2022 (48%). Whilst there are now several longitudinal and repeat cross-sectional studies reporting before-and-after BMI changes showing a sharp increase in BMI or BMIz following the lockdowns (e.g. Brooks et al., 2021; Chang et al., 2021; Gwag et al., 2021; Hu et al., 2021; Jarnig, Jaunig, et al., 2022; Vogel et al., 2022; Wahl-Alexander & Camic, 2021; Weaver et al., 2021) we are only aware of one other longitudinal dataset that has re-measured the children more than a year after lockdowns (Jarnig, Kerbl, et al., 2022). Data from a similarly aged population (Jarnig, Kerbl, et al., 2022) measured children in the Septembers of 2019, 2020 and 2021, comparable times to our T0, T1 and T2. The pattern of increased BMIz at T1, then a non-significant change at T2 were reported, showing the difficulty in reversing the weight gain experienced by the children. Data from the English NCMP (repeat cross-sectional design) found that obesity in Year 6 (aged 10–11 years) children was highest in the North East and increased from 23.2% to 29.1% between 2019/20 (T0) and 2020/21 (T1) (NHS Digital 2021), decreased during the 2021/22 school year to 26.6% (T2 & T3) (NHS Digital, 2022), and continued to decline in 2022/23 (25.5%) (NHS Digital, 2023), a pattern that was repeated nationally. As our results follow the national picture, we can reasonably expect a continued shallow decrease in overweight and obesity.

We found an initial decrease in shuttles completed in the 20mSRT at T1, which returned to baseline levels at T2, 25 months after T0. By June 2022 (T3) the mean number of shuttles had increased. While there is a recognised impact of seasons on children's cardiorespiratory fitness (Carrel et al., 2007; Mann et al., 2020) and BMI, our data are encouraging, in that 20mSRT performance in some children may have reached the point it would have been at without the pandemic. The pronounced decline and concomitant increase in the individual-level 20mSRT data (Figures 2, 5) suggests a detraining effect with fitter children showing a more pronounced decrease in shuttles run, followed by a steady increase. We speculate that this may have been due to sport and physical activities stopping abruptly, then restarting when lockdown restrictions eased, since detraining occurs following a marked reduction in physical activity with the magnitude of changes dependent on fitness level and the duration of reduced activity (Mujika & Padilla, 2001). Further, the timepoints of T0–T2 demonstrated a detraining-retraining effect that is not always observed in highly trained individuals (e.g. Godfrey et al., 2005).

As with BMI, there are several studies now reporting on before-and-after-lockdown physical fitness levels (Chambonnière et al., 2021; Constantini et al., 2021; Eberhardt et al., 2022; Jurak et al., 2021; López-Bueno et al., 2021; Tsoukos & Bogdanis, 2022; Wahl-Alexander & Camic, 2021). Again, we are aware of only one longitudinal study that has followed-up

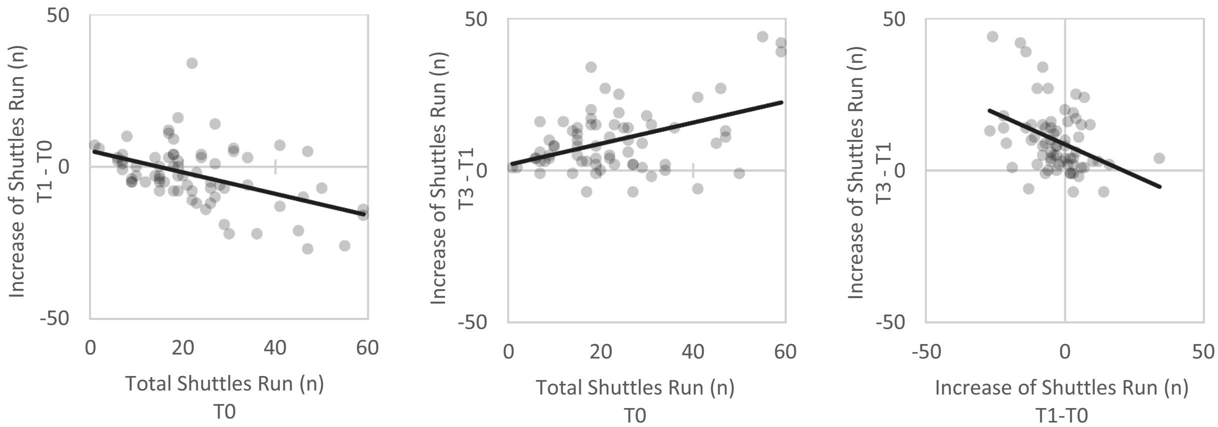


Figure 5. Associations between baseline (T0) shuttle run performance, increase in shuttle run performance between T0 and T1, and increase in shuttle run performance between T1 and T3. Second, additional analysis showed that sustained post-lockdown sport participation (reported playing in any sport club at T2 and T3) was associated with better 20mSRT at T3 ($r^2 = 14\%$, $p < 0.001$).

children further (Jarnig, Kerbl, et al., 2022) and direct comparisons are hampered by differing test protocols and assessment timings for some outcomes. The exception to this is for lower-body strength, where a large cohort ($n = 708$) of Austrian primary school children (aged 7 to 10 y at baseline) (Jarnig, Kerbl, et al., 2022) demonstrated a similar increase in lower body strength using the same protocol as we used (i.e., standing long jump increased 8% from September 2019 to September 2020 and 10% by June 2021). They also showed an increase of upper body strength but with a different protocol to us (i.e., 15% [September 2020] and 26% [June 2021] increases from pre-covid levels on a 1 kg medicine ball push test). In contrast to our findings, Jarnig et al. (2022) observed aerobic performance (measured with the 6 minute run) was still, on average, 6% below pre-COVID level by June 2021 (Jarnig, Kerbl, et al., 2022). It will be interesting to see further longitudinal data from this group and assess whether the children follow the same recovery trajectory as ours.

In contrast to our 20mSRT data, average standing broad jump distance and handgrip strength improved at each timepoint as would have been expected in the absence of the pandemic due to increasing age (De Miguel-Etayo et al., 2014; G. Tomkinson et al., 2017; G. R. Tomkinson et al., 2018). This potentially highlights the disparate trajectories observed over the pandemic for different aspects of physical fitness. We have previously suggested that 20mSRT performance may have been more susceptible to decline over the lockdowns than muscular fitness components (i.e., standing broad jump and handgrip strength) (Basterfield et al., 2022), possibly due to type of activities performed (or not) during the lockdown periods. Indeed, global data on changes in children and adolescents' physical activity during the pandemic indicate a 20% reduction in duration in engagement in physical activity, with the largest changes observed for higher intensity activities (−32%, equivalent to a 17-minute reduction in daily moderate-to-vigorous physical activity) (Neville et al., 2022). Encouragingly, however, our extended follow-up data (i.e., T3) indicate that 20mSRT performance is now improving alongside standing broad jump and handgrip strength, despite the observed increase in BMI and BMIz. The exact reasons for this are unclear, as while we would expect an increase in height and weight in a growing population, increases in fat or fat-free mass could have opposing effects on fitness outcomes ((Ceschia et al., 2016; Sherriff et al., 2009) (i.e., greater fat mass leading to lower broad jump and 20mSRT scores and greater fat-free mass leading to higher scores). To elucidate this, however, would require the use of a body composition measure which can detect changes in fat and fat-free mass, which BMI cannot. It is also possible that our extended follow-up scores are impacted by increasing physical activity levels, with some recent data suggesting children's moderate-to-vigorous physical activity is now returning to pre-pandemic levels (Jago et al., 2023).

Generally, HRQoL in European children decreases year-on-year (Michel et al., 2009), therefore our observations for most domains of HRQoL are as expected. The decrease in overall Physical Wellbeing is not unexpected, given the increases in overweight (Basterfield et al., 2022). There was perhaps less change overall than we might have anticipated under the circumstances, and there are a number of potential reasons. First, we measured during periods when the children were at school, reducing negative mental health outcomes (Shum et al., 2021). Second, other areas of mental wellbeing may have played a protective role, such as emotion regulation, family functioning and a level of social support (Marchi et al., 2021). The increase in score seen in Parents & Autonomy may present an unexpected positive outcome from the lockdowns.

This study has a number of strengths, including the longitudinal design in a relatively deprived population. Additionally, the amount of missing data at T3 was minimal. A small number of children ($n = 2$) refused the weight measurement at T0, and 9 were absent, and these were found to be not-at-random; children with a higher BMIz at follow-up were more likely to be missing (for any reason) at baseline; T0 BMIz and overweight/obesity were likely slightly higher than reported. The higher 20mSRT at T3 may have been higher due to seasonality; future follow-up should help answer that question. The ethnic background of our participants reflects the geographic area, but results may not be applicable to other ethnicities or regions. Due to older children from previous waves of data collection moving schools, our sample size is relatively small. A recent Delphi study of international fitness experts called for more longitudinal studies, and these data make a valuable contribution (Lang et al., 2022).

Conclusion

Between October 2019 and June 2022, a period that included the COVID-19 lockdowns in England, children's BMIz increased rapidly and has remained elevated. In the same time frame, 20mSRT performance decreased, then slowly increased. These data highlight a real and immediate need for interventions to reduce overweight and obesity in children in the North East of England, and more broadly to improve health and fitness behaviours early in childhood to improve the long-term health outcomes and build resilience to future emergencies and disruptions to health behaviours.

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Data sharing policy

Data are available from the corresponding author upon request.

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Appendix 1. Estimated marginal mean differences between timepoints, with p values with Tukey adjustments for multiple comparisons

Body mass index (BMI)

Comparison	BMI (% of comparator)	Age- and Sex-normalised BMI (z)
T1 - T0	107.8% (105.6%, 110%) $p < 0.0001$	0.26 (0.105, 0.415) $p = 0.0001$
T2 - T0	111.5% (109.2%, 113.8%) $p < 0.0001$	0.242 (0.087, 0.398) $p = 0.0004$
T3 - T0	112.5% (110.1%, 114.8%) $p < 0.0001$	0.176 (0.02, 0.331) $p = 0.0196$
T2 - T1	103.4% (101.4%, 105.5%) $p = 0.0001$	−0.018 (−0.166, 0.131) $p = 0.9897$
T3 - T1	104.4% (102.3%, 106.4%) $p < 0.0001$	−0.084 (−0.232, 0.063) $p = 0.4515$
T3 - T2	100.9% (98.9%, 102.9%) $p = 0.6571$	−0.067 (−0.215, 0.082) $p = 0.6548$

Fitness outcomes

Comparison	Shuttles (% of comparator)	Standing Broad Jump (cm)	Grip (% of comparator)	Sit and reach (cm)
T1 - T0	87.7% (78.2%, 98.3%) $p = 0.017$	8.4 (4.7, 12.1) $p < 0.0001$	112.3% (104.0%, 121.2%) $p = 0.0006$	−2.2 (−3.3, −1.0) $p < 0.0001$
T2 - T0	106.8% (95.6%, 119.2%) $p = 0.4243$	11.2 (7.5, 14.9) $p < 0.0001$	130.9% (121.2%, 141.2%) $p < 0.0001$	−0.5 (−1.6, 0.7) $p = 0.7034$
T3 - T0	128.9% (115.7%, 143.5%) $p < 0.0001$	13.6 (9.9, 17.4) $p < 0.0001$	144.9% (134.4%, 156.4%) $p < 0.0001$	0.0 (−1.2, 1.1) $p = 0.9995$
T2 - T1	121.8% (109.1%, 135.8%) $p < 0.0001$	2.8 (−0.8, 6.4) $p = 0.1773$	116.5% (108.1%, 125.6%) $p < 0.0001$	1.7 (0.6, 2.8) $p = 0.0004$
T3 - T1	147% (132.2%, 163.5%) $p < 0.0001$	5.2 (1.6, 8.8) $p = 0.0012$	129.0% (119.9%, 139.0%) $p < 0.0001$	2.1 (1.0, 3.2) $p < 0.0001$
T3 - T2	120.7% (109%, 133.6%) $p < 0.0001$	2.4 (−1.2, 6.0) $p = 0.3152$	110.7% (102.8%, 119.4%) $p = 0.0023$	0.4 (−0.7, 1.5) $p = 0.7507$

Health-related quality of life domains

Comparison	Physical (T)	Psychological (T)	Parents and Autonomy (T)	Peers (T)	School (T)
T1 - T0	−3.12 (−6.25, 0.00) $p = 0.0504$	−0.22 (−3.92, 3.48) $p = 0.9987$	2.65 (−0.94, 6.24) $p = 0.2265$	−0.82 (−5.1, 3.46) $p = 0.9601$	−4.15 (−7.99, −0.30) $p = 0.029$
T2 - T0	−5.8 (−8.99, −2.61) $p < 0.0001$	0.33 (−3.45, 4.11) $p = 0.9959$	4.78 (1.12, 8.45) $p = 0.0047$	−1.22 (−5.59, 3.15) $p = 0.8886$	−0.68 (−4.60, 3.24) $p = 0.9696$
T3 - T0	−6.25 (−9.41, −3.09) $p < 0.0001$	−0.68 (−4.41, 3.06) $p = 0.966$	7.43 (3.81, 11.05) $p < 0.0001$	−0.12 (−4.44, 4.19) $p = 0.9999$	−1.25 (−5.12, 2.63) $p = 0.8394$
T2 - T1	−2.68 (−5.78, 0.43) $p = 0.1184$	0.55 (−3.13, 4.23) $p = 0.9801$	2.13 (−1.44, 5.71) $p = 0.4118$	−0.40 (−4.69, 3.90) $p = 0.9951$	3.47 (−0.38, 7.31) $p = 0.0933$
T3 - T1	−3.13 (−6.18, −0.07) $p = 0.0425$	−0.46 (−4.07, 3.16) $p = 0.9881$	4.78 (1.27, 8.29) $p = 0.0029$	0.70 (−3.53, 4.92) $p = 0.974$	2.90 (−0.88, 6.68) $p = 0.1956$
T3 - T2	−0.45 (−3.57, 2.67) $p = 0.9822$	−1.01 (−4.70, 2.69) $p = 0.8953$	2.64 (−0.94, 6.23) $p = 0.2271$	1.09 (−3.22, 5.41) $p = 0.9133$	−0.56 (−4.42, 3.29) $p = 0.9815$

Appendix 2. Raw and age- and sex-normalised body mass index (BMI), physical fitness, and physical health related quality of life (KIDScreen–27) for each child (light grey line) across each assessment (T0: October 2019, T1: November 2020, T2: November 2021, T3: June 2022). The cohort mean is indicated by open black circles. See Figures 1–3 for model estimates.