Physical activity and asthma symptom control in children during COVID-19 lockdown: A feasibility study

Xiaorong Ding[1,2] iD , Maxine E Whelan[3] iD , David A Clifton[2,4]
and Tingting Zhu[2]

Abstract

Objective: The aim was to evaluate the impact of the COVID-19 lockdown on physical activity (PA) and asthma symptom control in children.

Methods: We conducted a single-cohort observational study on 22 children with a median age of 9 (8–11) years with a diagnosis of asthma being included in the study. Participants were asked to wear a PA tracker for 3 months; during the same 3-month period, the Paediatric Asthma Diary (PAD) was administered daily and the Asthma Control (AC) Questionnaire together with the mini-Paediatric Asthma Quality of Life (AQoL) Questionnaire administered at weekly intervals.

Results: Compared with the pre-lockdown period, there was a significant reduction in PA levels after the lockdown began. Daily total steps reduced by about 3000 steps ($p < 0.001$), very active minutes by 9 min ($p < 0.001$) and fairly active minutes almost halved ($p < 0.001$); while asthma symptom control marginally improved, with the AC and AQoL score improving by 0.56 ($p < 0.005$) and 0.47 ($p < 0.05$), respectively. Further, for those with AC score higher than 1, PA was positively associated with asthma control both before and after the lockdown.

Conclusions: This feasibility study suggests that PA engagement of children with asthma is negatively affected during the pandemic, but the beneficial effect of PA on asthma symptom control potentially sustains even during a lockdown period. These findings emphasize the importance of wearable device to monitor longitudinal PA and thus better management of PA for achieving the best outcome of asthma symptom control.

Introduction

Asthma is the most common long-term condition among children globally,[1] and UK has the highest prevalence rates of asthma symptoms in children worldwide,[2] with more than one million children suffering from asthma.[3] Effective paediatric asthma management is important given asthma is a common reason for urgent admission to hospital in children.[2,4] According to the National Institute for Health and Care Excellence (NICE), a key component to asthma management is participation in regular physical activity (PA) alongside activities such as medication adherence.[5]

When comparing PA levels in children with asthma with children without asthma, there is contradictory evidence.

Some studies report that children with asthma are more likely to accumulate fewer than 30 min of activity per

[1]School of Life Science and Technology, University of Electronic Science and Technology of China, Chengdu, China
[2]Institute of Biomedical Engineering, University of Oxford, Oxford, UK
[3]Centre for Intelligent Healthcare, Coventry University, Coventry, UK
[4]Oxford Suzhou Centre for Advanced Research, Jiangsu, China

Corresponding author:
Xiaorong Ding, School of Life Science and Technology, University of Electronic Science and Technology of China, Qingshuihe Campus, No.2006, Xiyuan Ave, West Hi-Tech Zone, 611731, Chengdu, Sichuan, China.
Email: xiaorong.ding@uestc.edu.cn

day.[6] This might be because childhood symptoms of asthma negatively interfere with PA involvement.[7] In contrast, a meta-analysis of accelerometer data revealed an overall mean difference of 0.01 activity counts per minute in children and adolescents.[8] Despite the mixed evidence-base, the potential reasons why activity may be lower in children with asthma are much clearer. As an example, caregivers can perceive PA as a threat rather than a beneficial activity by misinterpreting a child's breathlessness.[9] More than one in three parents impose restrictions on their child's PA involvement[10] and more than 60% of parents explicitly declare their child's health as a barrier to doing exercise.[11] By monitoring PA levels in children with asthma, it is possible to evaluate the relationship of PA with asthma control, and whether there may be an optimal level of PA to keep asthma under control. Therefore, monitoring of PA in parallel to asthma indicators is warranted to help promote PA participation in children with asthma.

Monitoring of behaviour alongside asthma symptoms is increasingly common. Van der Kamp and colleagues revealed that asthma symptoms could be accurately assessed at home by combining parameters from spirometry, a PA tracker and electrocardiography device.[12] Another study analysed wearable data on PA and sleep and demonstrated associations with asthma symptoms and that, together, this information could inform a tailored asthma management plan.[13] Within the COVID-19 context, van der Kamp emphasizes at-home monitoring suitably complementing existing healthcare given the potential for tailoring.[14]

During the COVID-19 pandemic, opportunities for children to meet PA guidelines were negatively affected. Notably, government-enforced measures such as physical distancing and school closures had a part in this. Evidence to date has suggested children went to bed later and woke up later, while screen time increased and activity levels were very low.[15,16] Across the whole population, a systematic review highlighted clear changes in PA and sedentary behaviour.[17] Longitudinal monitoring of PA and asthma symptoms spanning before the implementation of 'stay at home' in the UK into the first few weeks of a national lockdown could reveal important patterns about PA, asthma control/symptoms and asthma-related quality of life. Hence, the aim of this study was to evaluate the impact of the pandemic lockdown on PA and asthma symptom control with a wearable activity tracker and online survey data, specifically, to analyse the association of PA and asthma control in children comparing a period of regular PA and a period of forced reduced PA.

Methods

The methods are written in accordance with the 'strengthening the reporting of observational studies in epidemiology' (STROBE) guidelines.

Study design and governance

A longitudinal observational study involving children with asthma was conducted. The study was originally planned to investigate the feasibility of wearable trackers to motivate children in asthma to be more active, but the COVID-19 pandemic impacted our ability to deliver this study. In response, we conducted the original study as planned but instead used the data to analyse the impact of the pandemic lockdown on PA and asthma symptom control in children. Ethical approval was approved by the Central University Research Ethics Committee at the University of Oxford (R42332/RE001). We sought assent from all participants, and written informed consent from the child's parents or guardians to take part. Participants and parents/guardians were informed that they could withdraw from the study at any time without providing a reason.

Study size

A target of 30 children was implemented for the study. Due to COVID-19 and the national lockdown in the UK preventing further in-person baseline visits, recruitment ceased at 22 participants. Participants took part in the Fitbit intervention for three months before completing four weeks' follow-up.

Participants and recruitment

All participants were aged 6–14 years old, self-reported a diagnosis of asthma, and without having experienced an asthma attack in the preceding year. Participants must have been living in Oxfordshire or London and had access to a smartphone compatible with the Fitbit application (app) to be eligible to take part (e.g. parent's or guardian's smartphone). Recruitment took place from January 2020 to March 2020, and data was collected during January 2020 to June 2020. Baseline visits occurred at the University of Oxford with subsequent data collection continuing remotely via wearables, smartphones and online surveys.

Participants were recruited using convenience sampling. Acumen, a professional recruitment company in the UK, was used to identify potentially eligible participants from their database. Individuals interested in taking part were screened for eligibility by the recruitment company by telephone or email. If eligible, these individuals were booked in for their in-person baseline visit with the research team. All participants were incentivized to take part using a £150 voucher and getting to keep the Fitbit after the study period ended.

Self-monitoring PA with wearable tracker

The participants monitored their PA using a wrist-worn wearable activity tracker (Fitbit Inspire HR). The Fitbit Inspire HR is a slim fitness tracker that can track step count and detect

exercise (with accelerometer), in addition to monitor heart rate (with optical sensor). Its battery life is about one week. Smartphones of the parent/caregiver to the participant were

Table 1. Demographic and baseline clinical characteristics of the subjects.

Characteristics	Median (IQR) or n (%)
Age (years)	9 (8–11)
Gender	
Male	16 (72.7%)
Female	6 (27.3%)
Home life	
Single parent	9 (40.9%)
Both parents	13 (59.1%)
Diagnosis length (years)	4.8 (3.4%)
Asthma severity	
Mild intermittent	3 (13.6%)
Mild persistent	9 (40.9%)
Moderate persistent	9 (40.9%)
Severe persistent	1 (4.5%)
Asthma attacks and hospitalizations in the 6 months preceding participation	
Number of asthma attacks	1 (0–2)
School days missed due to asthma	1 (0–5)
Times of hospital visit	1 (0–2)
Times of hospital admission	0 (0–1)
Asthma medication regimen	
Preventer inhaler	19 (86.4%)
Reliever inhaler	19 (86.4%)
Long-acting reliever inhaler	2 (9.1%)
LTRA tablet	5 (22.7%)
Long-term steroid tablet	1 (4.5%)
Add-on therapy (e.g. theophylline)	1 (4.5%)

used to set up each Fitbit and a researcher-held Gmail account was used to enable the research team to access the Fitbit data syncing to Fitabase. After consenting to participate, each participant received a Fitbit tracker. The parents or guardians of the participants were supported in installing the Fitbit app, synchronizing the device to their app with connection to the designated Fitbit account. The participants were asked to wear the Fitbit for three months, from morning until bedtime. Three months was chosen to allow for longitudinal monitoring to enable patterns of health and behaviour to be revealed. Parents/guardians were encouraged to synchronize the data from the Fitbit to the Fitbit app once a day to minimise data loss. During the 3-month period, there were no planned reminders but if participants had more than a week without registered activity (e.g. due to lack of any synchronization), the research team contacted the parents/guardians by text message to check there were no technical issues. Participants were asked to set an appropriate activity goal via the app.

Procedures

All participants completed a baseline questionnaire, which collected information about the participant's age, gender, asthma diagnosis (including years since diagnosis and severity), prescribed asthma medication, quality of life, and PA levels. During the 3-month data collection period, participants were asked to complete the Paediatric Asthma Diary (PAD) every day and the Asthma Control (AC) Questionnaire and mini-Paediatric Asthma Quality of Life (AQoL) Questionnaire every week using a Google Form. Higher scores for PAD and AC reflected worse asthma symptom control and higher scores for the AQoL indicated better quality of life. Reminders by text message were sent to participants when their responses were not provided within a week of the due date. After this 3-month period, participants were asked to complete the International Physical Activity Questionnaire at 1-week, 2-weeks and 4-weeks follow-up. Minute-level PA was collected via the Fitbit tracker, with support from Fitabase. These data included step count, heart rate and activity intensity determined by a proprietary algorithm from Fitbit. Paper-based forms were stored securely at the University of Oxford in a locked cabinet.

Data analysis

The analysis was undertaken with Python 3.8. The data from each participant was identified with a subject ID. Subjects who provided $\geq 40\%$ missing data over the three months (i.e. more 5 out of 12 weeks) were excluded from the analysis. For each participant, each calendar day was characterized by PA metrics including Fitbit-derived total number of steps, total distance, 'very active' distance, 'moderately active' distance, 'lightly active' distance, 'very active' minutes, 'fairly active' minutes, 'lightly active' minutes, and

Table 2. Response rate and available data at study time points.

Measures	Baseline (compliance rate)	3 months (compliance rate)	Follow-up (compliance rate)
Paediatric Asthma Diary	-	1501 responses (75.8%)[b]	-
Asthma Control Questionnaires	22 participants (100%)[a]	197 responses (74.6%)[c]	-
Asthma Quality of Life Questionnaire	22 participants (100%)[a]	197 responses (74.6%)[c]	-
Physical Activity Questionnaire	22 participants (100%)[a]	-	64 of 66 responses (97%)
Wearable Tracker Adherence	-	1393 of 1980 days (70.35%)	-

a Out of a possible 22 individuals.
b Out of a possible 1980 diaries (calculated by 22 individuals each completing 90 diaries).
c Out of a possible 264 questionnaires (calculated by 22 individuals each completing 12 weekly questionnaires).

sedentary minutes, and PAD score (evaluating daily asthma control), where different kinds of 'active' distance/minutes denote distance/time spent performing moderate to vigorous PA defined by Fitbit's proprietary algorithm; and each week was characterized by weekly average PA metrics, AC score and AQoL score.

Median (IQR) of number of steps, distance, minutes in PA per day, as well as PAD per day, AC and AQoL score per week for the entire period were calculated for each subject and then averaged for all the subjects before and after the lockdown (lockdown implemented on 24th March 2020). Scatter plots were used to depict the relationship between PA metrics and AC evaluation scores. We used second-order polynomial model to fit the data of PA metrics with AC and AQoL scores. Wilcoxon sign-ranked test at 0.05 significance level was conducted to determine differences between the metrics and scores before and after the lockdown.

Results

A total of 22 children with asthma provided data between 10 January 2020 and 19 June 2020, covering the period of the first lockdown (24th March 2020 to 19th April 2020) during the COVID-19 pandemic in the UK. The characteristics of the subjects are listed in Table 1, with data concerning participant compliance to completing the diaries and adhering to wear the activity tracker presented in Table 2. We excluded 8 participants from the initial sample of 22 participants for the analysis of PA before and after the lockdown, because seven of the eight had a compliance rate of PA recording and reported weekly asthma questionnaire lower than 40%, that is, less than 5 out of 12 weeks, and one subject's PA data did not cover the first lockdown as it only reported data prior to it. Among the 14 subjects used for PA analysis, we further removed one subject for analysing AC and the relationship between PA and AC, as this subject's asthma control data did not cover the period after the pandemic lockdown. Reasons for the

missing data included an absence of synchronisation (leading to data loss), low adherence to wearing the device and filling the questionnaire and loss of the wearable tracker.

PA pattern before and after the lockdown

Figure 1 delineated the total steps variations three weeks before and after the first round of lockdown for one representative subject. As can be seen, there was a marked decrease in 'very active' and 'fairly active' minutes one week before and after the occurrence of the lockdown.

Figure 2 shows the PA levels of all participants before and after the first lockdown in March 2020. It can be observed that PA levels declined among almost all the participants and to varying extents.

Table 3 shows the median (IQR) of overall activity levels of participants before and after the first lockdown (implemented on 24th March 2020) during the COVID-19 pandemic. Significant reductions in PA levels were noted after the lockdown began, compared with the pre-lockdown periods. Specifically, total steps reduced by ~3500 steps per day, total distance by 2.70 km, very active minutes by 13 min, fairly active minutes almost halved. Sedentary minutes increased by more than 1.5 hour (around 90 min) but this change was not statistically significant ($p = 0.24$).

Asthma symptom control before and after the lockdown

With regard to changes in asthma control before and after the lockdown, Figure 3 portrays the AC and AQoL score variation of one exemplary individual. As shown, AC score reduced and the AQoL score increased the week immediately after the lockdown date which appeared to remain for around 4 weeks before receding towards their initial score.

Figure 4 shows the comparison of AC score before and after the first lockdown for each participant. Apart from one participant, AC score reduced after the lockdown.
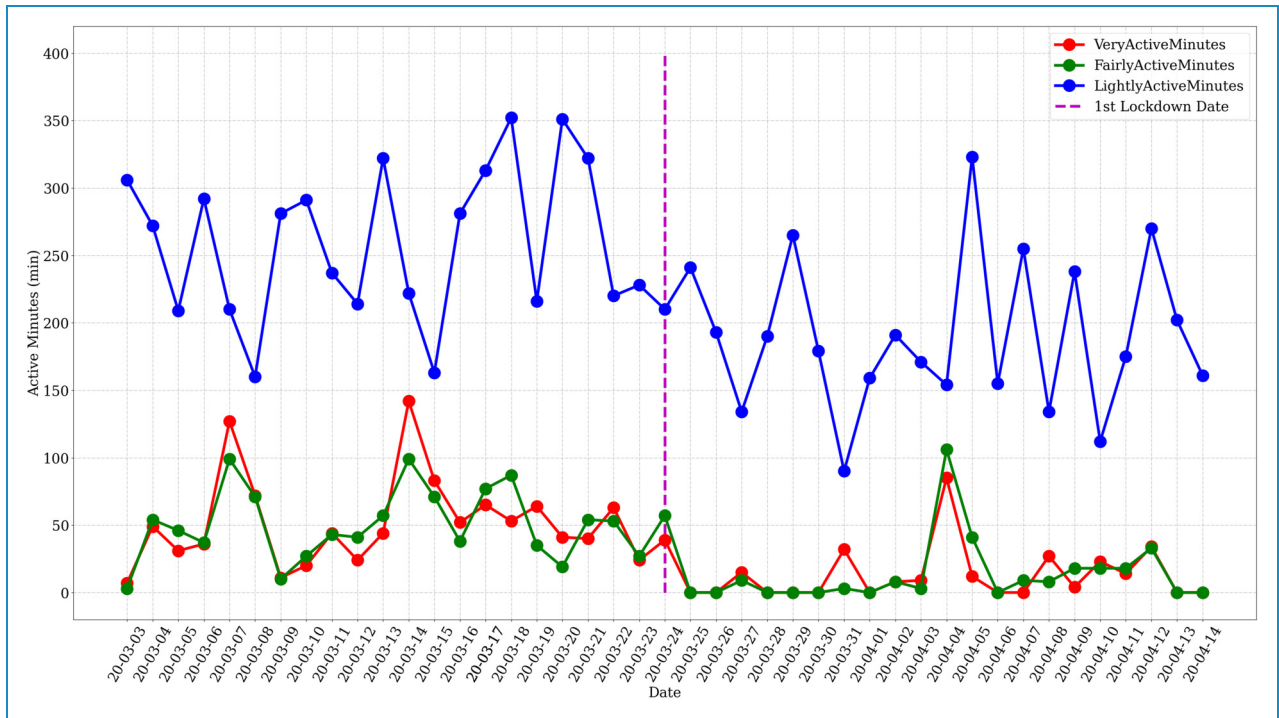
Figure 1. Physical active minutes of one representative participant three weeks before and after the first lockdown.
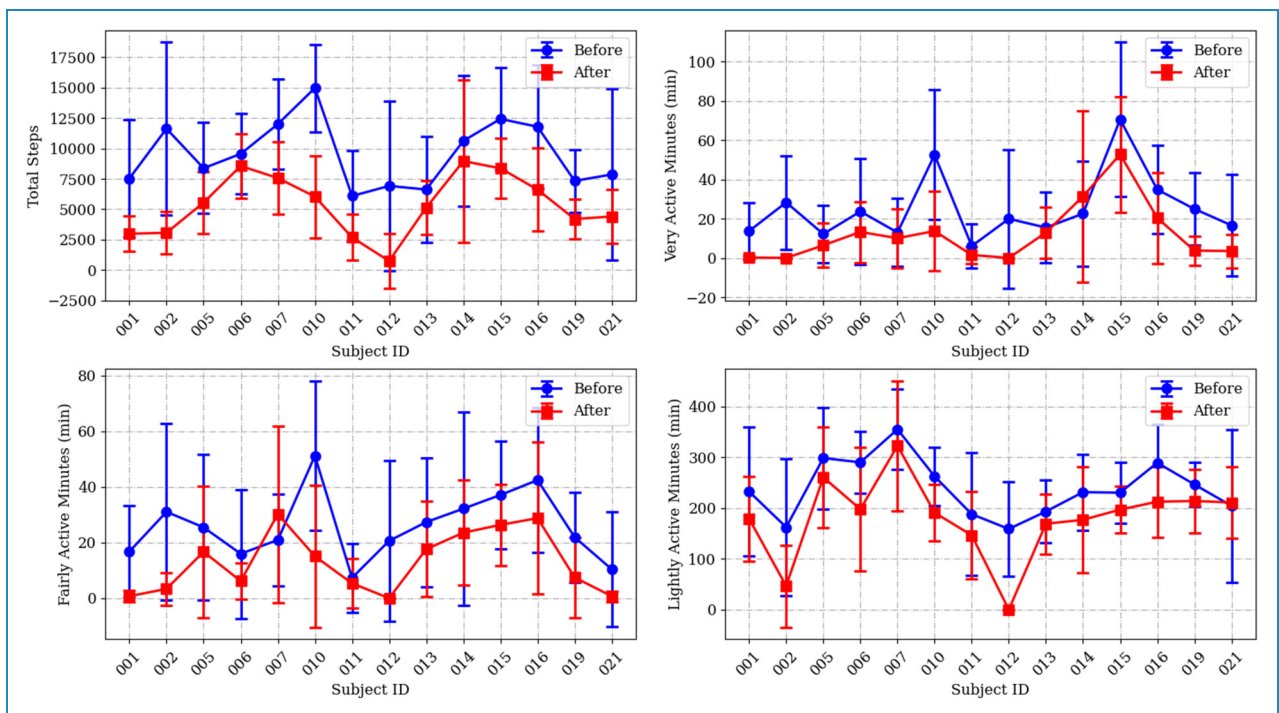

Figure 2. PA levels of each individual participants before (blue) and after (red) the first lockdown.

Likewise, AQoL score increased for all the participants except for one or two participants (Figure 5). This pattern was also observed for the sub-scores of the AQoL, including symptom score, emotion score and activity score.

The analysis revealed that asthma symptom control did not change (Table 4). More specifically, asthma symptom control marginally improved, with the AC and AQoL score improving by 0.50 and 0.55 units, respectively, but

Table 3. Daily physical activity level three weeks before and after the pandemic.

Physical activity level metrics	Before lockdown Median (IQR)	After lockdown Median (IQR)	Test statistic	*P*-value
Total steps	8969 (7384–11749	5344 (3353–7332)	0.0	<0.001
Total distances (km)	6.56 (5.39–8.53)	3.87 (2.43–5.32)	0.0	<0.001
'Very active' distances (km)	1.40 (0.99–2.06)	0.35 (0.12–0.97)	8.0	<0.001
'Moderately active' distance (km)	0.92 (0.72–1.37)	0.35 (0.15–0.66)	0.0	<0.001
'Lightly active' distance (km)	3.91 (3.24–4.69)	2.60 (2.18–2.87)	0.0	<0.001
'Very active' minutes (min)	21.26 (14.15–27.50)	8.25 (2.02–13.61)	5.0	<0.005
'Fairly active' minutes (min)	23.66 (17.70–31.86)	11.24 (3.83–22.04)	4.0	<0.001
'Lightly active' minutes (min)	232.11 (196.16, 282.64)	194.03 (171.15–212.25)	1.0	<0.001
Sedentary minutes (min)	702.21 (622.83–877.47)	791.03 (660.42–934.07)	33.0	0.24
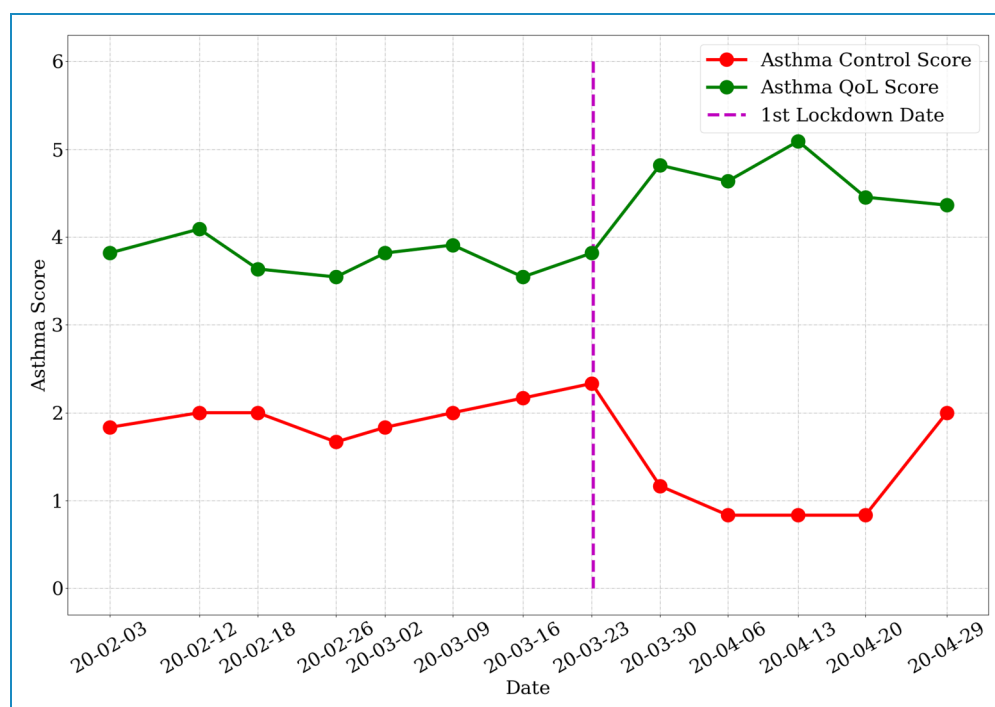
Figure 3. The weekly asthma control (AC) and asthma quality of life (QoL) score of one. Representative individual before and after the first lockdown.

no significant difference in PAD score before and after the lockdown.

Association of PA with asthma symptom control

With regard to the association of PA and asthma symptom control, Figure 6 shows the overall association between the four PA indicators and the AC score. As shown, there appears to be two clusters of participants being separated by the critical value of 1.0 of the AC score, which is at the cross-over point between 'well-controlled' and 'not well-controlled'. There are five participants in the 'well-controlled' cluster, and there seems no evident connection between PA indicators and asthma control score. For the 'not well-controlled' cluster, there is more than 60% of participants in this group, and there appears to be a distinct relationship between PA and
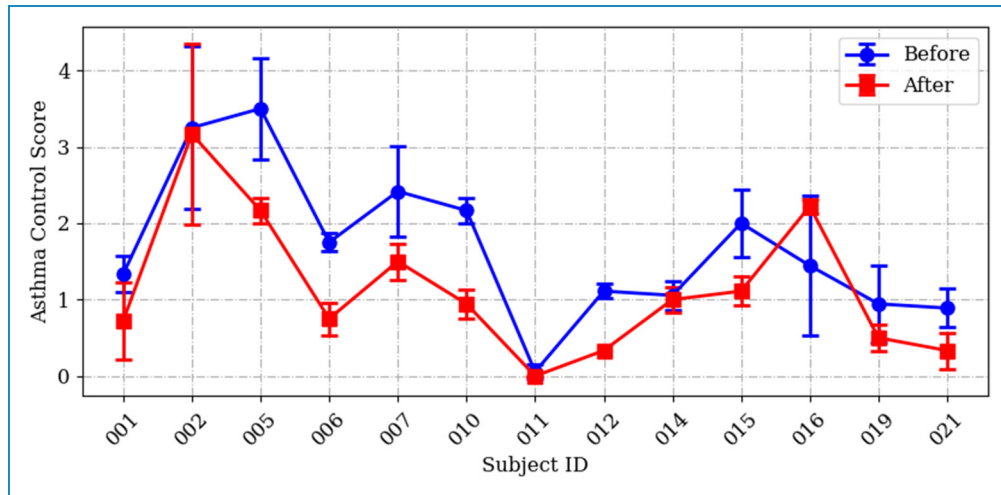
Figure 4. Asthma control score of each individual before and after the first lockdown.
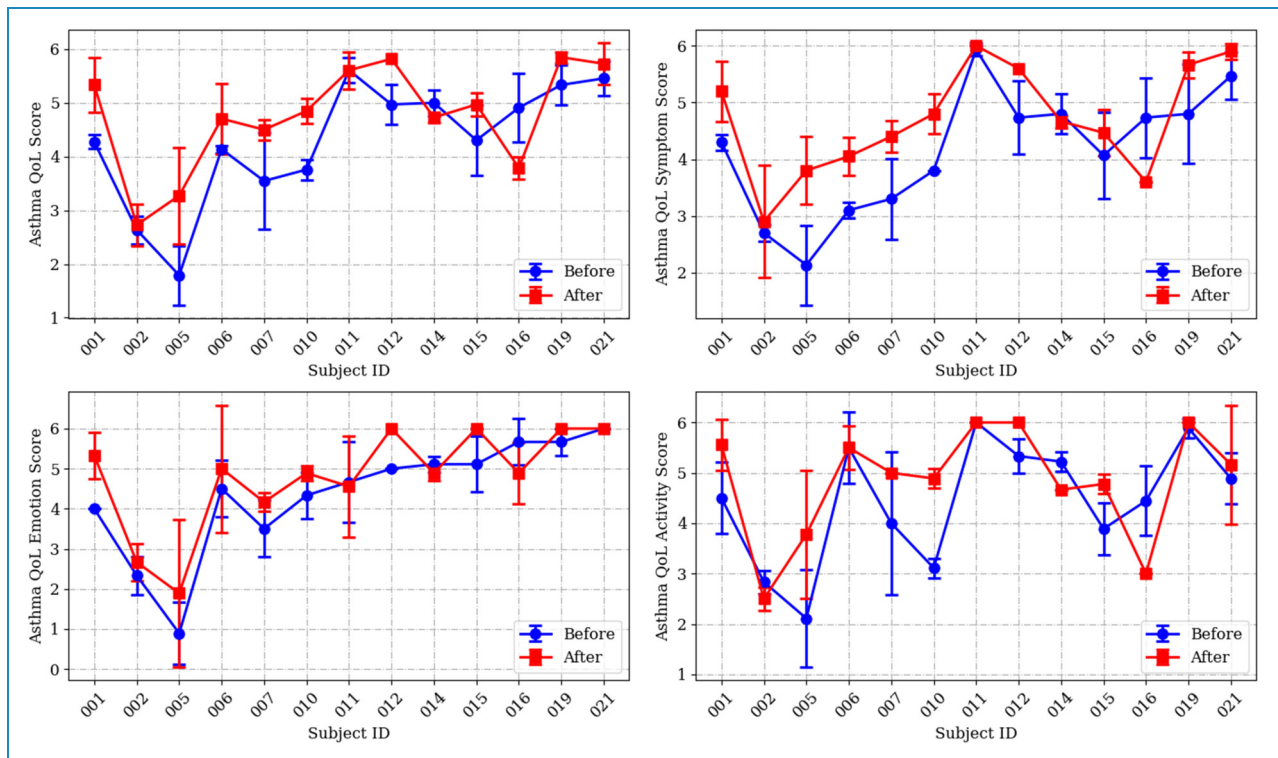

Figure 5. Asthma quality of life score of each individual before and after the lockdown.

AC score. In general, the PA metrics are reversely related to AC score, meaning the more active the child with asthma, the better their asthma symptom control. Further, by fitting the curve between those two kinds of variables, we demonstrated they had an inverted parabolic shape, potentially indicating an optimal PA level corresponding to the best asthma symptom control condition.

For the 'not well-controlled' cluster, we further analyzed the relationship between PA metrics and asthma score – including AC score and AQoL score – before and after the first round of lockdown (Figure 7). As can be observed, the shape of PA metrics and AC score for both before and after the lockdown were similar to an inverted parabolic curve. In particular for those before the lockdown, there appears to be a turning point where the relationship between the PA metrics become positively related. Taking one of the PA metrics – total steps as an example – when the subjects took <12,000 steps, AC decreased with the
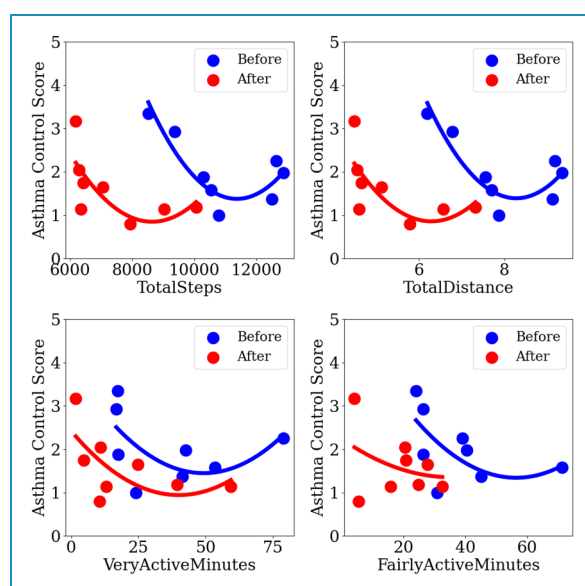
Table 4. Asthma symptom control before and after the first lockdown.

Measures	Before lockdown Median (IQR)	After lockdown Median (IQR)	Test statistic	P-value
Paediatric Asthma Diary (PAD) Score	2.95 (1.34–4.13)	2.33 (0.83–3.48)	29.0	0.15
Asthma Control (AC) Score	1.44 (1.05–2.17)	0.94 (0.50–1.50)	7.0	<0.005
Asthma Quality of Life (AQoL) Score	4.30 (3.76–5.00)	4.85 (4.50–5.61)	16.5	<0.05
AQoL Symptom Score	4.30 (3.30–4.80)	4.67 (4.05–5.60)	14.0	<0.05
AQoL Emotion Score	4.67 (4.00–5.11)	4.89 (4.56–6.00)	11.0	<0.05
AQoL Activity Score	4.50 (3.89–5.33)	5.00 (4.67–5.56)	16.0	0.13
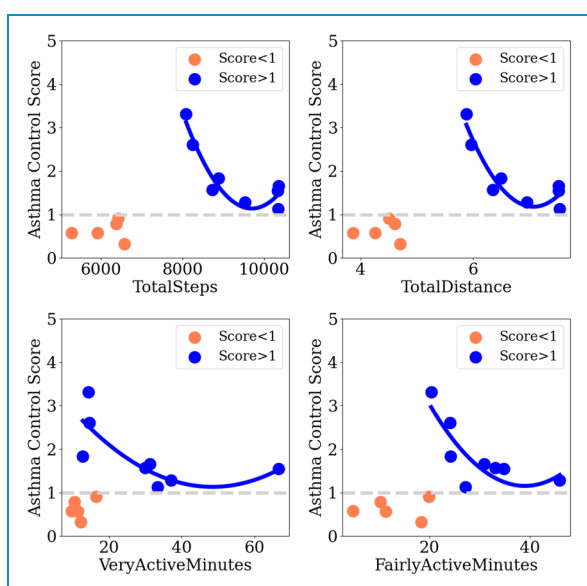
Figure 6. The scatter plot of physical activity indicator versus asthma control score for the overall data.

Figure 7. The association between physical activity and symptom control before (blue) and after (red) the 1st lockdown for participants whose AC score was over one before the lockdown.

increase of total steps; whereas for subjects who took more than 12,000 steps, AC score increased with an increase in total steps. Likewise, asthma symptom control seemed to be improved with the increase of PA level after the lockdown in general; however, the degree is not as significant as before. And the overall PA levels were reduced for these subjects after the lockdown as compared with before.

The PA levels and asthma QoL score varied in the same way before and after the lockdown. As illustrated in Figure 8, asthma QoL augmented when subjects became more active. The change seen was similar to that observed for asthma control. That is, asthma QoL improved with an increase in PA within a certain scope, and once PA level exceeded the limit, the asthma QoL score tended to decrease; this phenomenon is seen in total steps and total distances. Though the PA levels decreased significantly after lockdown, the variation trends of

asthma QoL with PA levels were almost unanimously consistent with those recorded before the lockdown.

Discussion

We investigated the influence of the first COVID-19 lockdown in the UK on longitudinal PA, asthma symptom control and their relationships in children with asthma with a wearable tracker. Our findings suggest that the lockdown restrictions had a dramatic impact on both PA levels and asthma symptom control, and confirms the positive incidence of being active and asthma control even during the lockdown period.

Compared with the weeks running up to the first COVID-19 lockdown in the UK, there was a significant reduction in the PA levels of children with asthma after
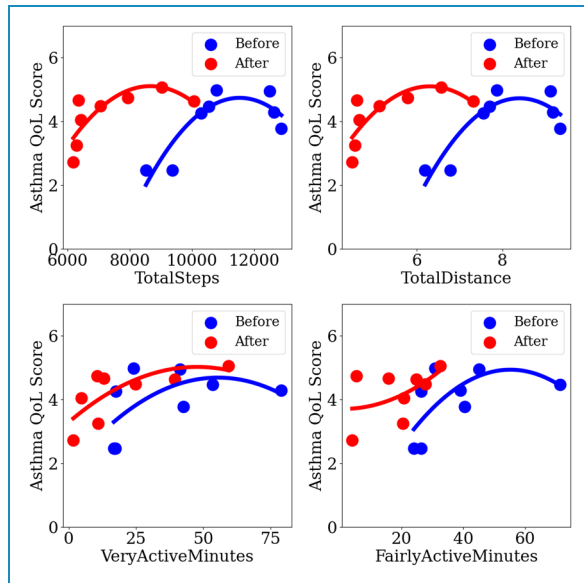
Figure 8. The association between physical activity and asthma quality of life (QoL) score before and after the 1st lockdown for participants whose AC score was over one before the lockdown.

the lockdown. Our findings correspond well to the findings of a previous study by Stockwell et al.,[15] who reported PA levels decreased during the COVID-19 lockdown across adults and children. In studies focusing on children, a study of >1000 participants in Germany revealed that 4–17 year old children self-reported declines in sports activity whilst recreational screen time increased.[18] This negative impact was also viewed to a greater extent in the adolescent participants. Another study in France, comprised >6000 participants who also self-reported reductions in PA during lockdown.[17] These other studies have much larger sample sizes; however, they are reliant upon self-report disclosure and retrospective recall. Having used a wearable tracker, our findings are helpfully able to demonstrate device-based PA before and after the implementation of a lockdown.

The other important finding to this study is that asthma symptom control and quality of life generally improved when children with asthma became more active. This is especially apparent among children whose asthma condition was not well-controlled (i.e. those with asthma control score being above 1). For the not well-controlled group, PA seems to play a useful role in improving the asthma symptom control and quality of life, but under the condition that PA level is within a specific range. This result appears to contradict previous finding reported by Matsunaga et al.[19] who used PA questionnaire as the measure of PA, and the follow-up study by Kamps et al.[20] that evaluated PA with self-reported PA and seven days of wearable accelerometer, at the baseline when the subjects' asthma was uncontrolled and at the time asthma control was achieved with a predefined criteria,

respectively. However, the key difference between our study with these studies is that we evaluated PA with wearable tracker continuously for six months instead of at controlled timepoints. That is, we evaluated the cumulative response but not the status. In addition, PA evaluated by wearable tracker and questionnaire would result in different finding. As shown in our study, the PA indicators of the wearable tracker were significantly lower after the lockdown compared with before (Table 3), but it showed no difference in the activity score of the AQoL questionnaire (Table 4). We also found that when participants were more active their asthma symptom may have worsened as a result. For example, when the total steps were over 10,000, the asthma control score increased with increase of total steps (Figure 6). This indicates that children with asthma would potentially benefit from taking part in PA when the degree of participation is within an optimal scope (in doing so, avoiding any adverse effects on asthma control).

It is noteworthy also to acknowledge that the small cluster of well-controlled asthma participants was not as active as the well-controlled group. Possible reasons behind this could be that children feel no motivation to be more active if they have well-controlled asthma. Motivation alongside time constraints, weather and lower self-efficacy have all been noted as potential barriers to participation in PA.[21] On the contrary, it could be due to the children downplaying their asthma severity to avoid parental worry. Previous literature suggests that parental perception of vulnerability of their child due to asthma greatly impacts frequency of school absences and visits to the GP.[22] As the sample size in this study is limiting, we are unable to untangle this finding. Further research is needed to investigate the role of asthma control and PA in children disclosing a score of 'well controlled'. In addition, under the hypothesis that there is a positive relationship between PA and asthma control or asthma quality of life, both asthma control and asthma quality of life should have worsened after the lockdown since the subject became less active compared with before the lockdown. In other words, AC score should have expected to increase with a decrease in AQoL score after the lockdown in Figures 7 and 8, but it is the opposite as shown in Table 4. The reason for this contradiction is probably that the worsening of the asthma control and quality of life is counteracted by the improvement of them because of potential factors such as less virus infections and reduced pollution during the lockdown.

One limitation of this study is the sample size. The generalizability of our results is somewhat limited by the small sample of this pilot study. Though the study was over a prolonged amount of time for each individual, we could not recruit more than 22 subjects due to COVID-19 ceasing recruitment. Further, approximately 30% of participants had compliance rate lower than 15%, either for wearing the trackers or responding to the survey. The second

limitation is that our analysis only applies to children who has a mild or moderate asthma condition. Owing to safety reasons, we only included subjects who had a diagnosis of asthma that was not too severe. Therefore, our findings do not necessarily apply to individuals who have more severe forms of asthma, or to children who have experienced asthma attacks. Lastly, there may exist confounders affecting the relationship between PA and asthma control which were not included in our analyses. On the one hand, other than PA, asthma control in children may also depend on factors including, sex, age, BMI, living condition, asthma severity at baseline, rhinitis and medicine adherence.[23,24] On the other hand, there may be other potential confounding factors which might have had impact on asthma control such as less virus infections and reduced pollution during the lockdown, which we will consider in our future study and analyse the relationship between these factors and asthma control with multilevel regression models.

Conclusions

This feasibility study suggests that the wearable tracker could enable the continuous and longitudinal collection of PA data to study the population of children with asthma. The results show that the PA level of children with asthma significantly reduced while their asthma control slightly improved during the pandemic. PA appears to demonstrate a beneficial factor to asthma control and asthma quality of life to some degree, and this was sustained during a lockdown period. Further larger studies, in particular controlled clinical trials, are needed to reduce confounding variables and to further verify the hypothesis that appropriate level of PA can improve asthma control in children at different stages.

Contributorship: XD was mainly responsible for this study. She conceptualized the study, guided the overall development and implementation of the wearable tracker intervention study. For this paper, XD guided the preparation, performed the data analysis, framed the interpretation of the findings and wrote the paper. MW contributed to developing the ethics application, the study design and data interpretation, and revised the paper. DC contributed to conceptualizing the study design and revised the paper. TZ contributed to conceptualizing the study design and presentation, interpretation of the findings and revised the paper.

ORCID iDs: Xiaorong Ding https://orcid.org/0000-0002-3269-2852
Maxine E Whelan https://orcid.org/0000-0002-9203-3162

Supplemental material: Supplemental material for this article is available online.

References

1. Asthma, https://www.who.int/news-room/fact-sheets/detail/asthma (accessed 6 June 2021).
2. Essential facts, stats and quotes relating to asthma, https://psnc.org.uk/services-commissioning/essential-facts-stats-and-quotes-relating-to-asthma/ (accessed 6 June 2021).
3. Asthma facts and statistics, https://www.asthma.org.uk/about/media/facts-and-statistics (accessed 6 June 2021).
4. Childhood asthma, https://www.england.nhs.uk/childhood-asthma/ (accessed 6 June 2021).
5. Asthma: diagnosis, monitoring and chronic asthma management, https://www.nice.org.uk/guidance/ng80/chapter/Recommendations#self-management (accessed 6 June 2021).
6. Lang DM, Butz AM, Duggan AK, et al. Physical activity in urban school-aged children with asthma. *Pediatrics* 2004; 113: E341–E346.
7. Walker TJ and Reznik M. In-school asthma management and physical activity: children's perspectives. *J Asthma* 2014; 51: 808–813.

8. Cassim R, Koplin JJ, Dharmage SC, et al. The difference in amount of physical activity performed by children with and without asthma: a systematic review and meta-analysis. *J Asthma* 2016; 53: 882–892.

9. Williams B, Hoskins G, Pow J, et al. Low exercise among children with asthma: a culture of over protection? A qualitative study of experiences and beliefs. *Br J Gen Pract* 2010; 60: e319–e326.

10. Dantas FMNA, Correia MAV, Silva AR, et al. Mothers impose physical activity restrictions on their asthmatic children and adolescents: an analytical cross-sectional study. *Bmc Public Health* 2014; 14: 1–7. DOI: 10.1186/1471-2458-14-287.

11. Glazebrook C, McPherson AC, Macdonald IA, et al. Asthma as a barrier to children's physical activity: implications for body mass index and mental health. *Pediatrics* 2006; 118: 2443–2449.

12. van der Kamp MR, Klaver EC, Thio BJ, et al. WEARCON: wearable home monitoring in children with asthma reveals a strong association with hospital based assessment of asthma control. *Bmc Med Inform Decis* 2020; 20: 1–12. DOI: 10.1186/s12911-020-01210-1.

13. Jiang B, Yi G, Xie M, et al. Exploring the association between self-reported asthma impact and Fitbit-derived sleep quality and physical activity measures in adolescents. *JMIR Mhealth Uhealth* 2017; 5: e105:101-111.

14. van der Kamp MR, Tabak M, de Rooij SEJA, et al. COVID-19: technology-supported remote assessment of pediatric asthma at home. *Front Pediatr* 2020; 8: 1–5. DOI: 10.3389/fped.2020.00529.

15. Sulyok M and Walker M. Community movement and COVID-19: a global study using Google's community mobility reports. *Epidemiol Infect* 2020; 148: e284.

16. Xiang M, Zhang ZR and Kuwahara K. Impact of COVID-19 pandemic on children and adolescents' lifestyle behavior larger than expected. *Prog Cardiovasc Dis* 2020; 63: 531–532.

17. Stockwell S, Trott M, Tully M, et al. Changes in physical activity and sedentary behaviours from before to during the COVID-19 pandemic lockdown: a systematic review. *BMJ Open Sport & Exercise Medicine* 2021; 7: e000960: 000961-000968.

18. Schmidt SCE, Anedda B, Burchartz A, et al. Physical activity and screen time of children and adolescents before and during the COVID-19 lockdown in Germany: a natural experiment. *Sci Rep-Uk* 2020; 10: 1–12. DOI: 1038/s41598-020-78438-4

19. Matsunaga NY, Oliveira MS, Morcillo AM, et al. Physical activity and asthma control level in children and adolescents. *Respirology* 2017; 22: 1643–1648.

20. Kamps A, Clevering A, Nieuwdorp B, et al. Asthma control is not associated with physical activity level in children with asthma during regular follow-up. *J Asthma* 2021; 59: 1–7.

21. Mancuso CA, Sayles W, Robbins L, et al. Barriers and facilitators to healthy physical activity in asthma patients. *J Asthma* 2006; 43: 137–143.

22. Spurrier NJ, Sawyer MG, Staugas R, et al. Association between parental perception of children's vulnerability to illness and management of children's asthma. *Pediatr Pulm* 2000; 29: 88–93.

23. Nordlund B, Melen E, Schultz ES, et al. Risk factors and markers of asthma control differ between asthma subtypes in children. *Pediatr Allergy Immunol* 2014; 25: 558–564. Article.

24. Leiria-Pinto P, Carreiro-Martins P, Peralta I, et al. Factors associated with asthma control in 121 preschool children. *J Investig Allergol Clin Immunol* 2021; 31. DOI: 10.18176/jiaci.0630.