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The impact of COVID-19 restrictions on accelerometer-assessed physical activity and sleep in individuals with type 2 diabetes

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Abstract

Aims: Restrictions during the COVID-19 crisis will have impacted on opportunities to be active. We aimed to (a) quantify the impact of COVID-19 restrictions on accelerometer-assessed physical activity and sleep in people with type 2 diabetes and (b) identify predictors of physical activity during COVID-19 restrictions.

Methods: Participants were from the UK Chronotype of Patients with type 2 diabetes and Effect on Glycaemic Control (CODEC) observational study. Participants wore an accelerometer on their wrist for 8 days before and during COVID-19 restrictions. Accelerometer outcomes included the following: overall physical activity, moderate-to-vigorous physical activity (MVPA), time spent inactive, days/week with ≥30-minute continuous MVPA and sleep. Predictors of change in physical activity taken pre-COVID included the following: age, sex, ethnicity, body mass index (BMI), socio-economic status and medical history.

Results: In all, 165 participants (age (mean±S.D = 64.2 ± 8.3 years, BMI=31.4 ± 5.4 kg/m², 45% women) were included. During restrictions, overall physical activity was lower by 1.7 m*g* (~800 steps/day) and inactive time 21.9 minutes/day higher, but time in MVPA and sleep did not statistically significantly change. In contrast, the percentage of people with ≥1 day/week with ≥30-minute continuous MVPA was higher (34% cf. 24%). Consistent predictors of lower physical activity and/or higher inactive time were higher BMI and/or being a woman. Being older and/or from ethnic minorities groups was associated with higher inactive time.

Conclusions: Overall physical activity, but not MVPA, was lower in adults with type 2 diabetes during COVID-19 restrictions. Women and individuals who were heavier, older, inactive and/or from ethnic minority groups were most at risk of lower physical activity during restrictions.

KEYWORDS
accelerometer, activity monitor, CODEC, coronavirus, MVPA, lockdown

Novelty statement
- Self-report data suggest COVID-19 restrictions have had a detrimental impact on physical activity.
- Studies in high-risk groups with objective measures of physical activity are lacking.

- We assessed physical activity with accelerometers before and during COVID-19 restrictions in people with type 2 diabetes.
- Although overall physical activity was lower, purposeful moderate-to-vigorous physical activity was maintained and the number of days per week with ≥30-minute continuous moderate-to-vigorous physical activity was higher.
- Women and individuals who were heavier, older, inactive and/or from ethnic minority groups were most at risk of lower physical activity during COVID-19 restrictions and could benefit from targeted support.

1 | INTRODUCTION

The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which causes coronavirus disease-2019 (COVID-19), has devastated global economies and fundamentally changed patterns of daily life for many. Restrictions put in place to limit the movement and interaction of people during the COVID-19 crisis will have impacted on opportunities to be active, potentially leading to decreases in physical activity and increased sedentary behaviour, which could have negative consequences for cardiometabolic health.[1,2] As people with type 2 diabetes mellitus have impaired cardiometabolic health and are already less active and more sedentary than those without the condition,[3] it is important to quantify the impact of the COVID-19 national lockdown on their physical activity.

Evidence is beginning to accumulate documenting a detrimental impact of COVID-19 restrictions on self-reported physical activity levels. For example, declines in total physical activity and in moderate-to-vigorous activity of approximately 35% and 23%, respectively, were reported by 2524 Italian participants completing an online survey.[4] A similar decline in total activity, but 60% decline in moderate-to-vigorous activity was self-reported by 143 physiotherapy professionals and students in an online survey in India.[5] The pattern of decline was similar in a small sample of adults with type 2 diabetes in Spain, with self-reported moderate-to-vigorous activity decreasing by 66% in men and 52% in women.[6]

As well as physical activity, restrictions will have disrupted other behaviours, e.g. time spent inactive including sedentary (sitting) behaviours. Self-reported sitting increased by 48% (men) and 21% (women) in adults with type 2 diabetes in Spain,[6] and nearly four-fold in physiotherapy students and professionals in India.[5]

To date, most research on change in physical activity during the COVID-19 pandemic has relied on self-report, with participants asked to recall their activity during and prior to heightened restrictions, exacerbating the well-documented limitations of self-report.[7] A small study of 26 heart failure patients that used device-based measures of activity also showed a 16% decrease in steps/day.[8] However, larger studies

in high-risk groups with objective measures are lacking, as are studies examining patterns of physical activity which may also be related to health.[9]

As well as identifying whether COVID-19 restrictions had a detrimental impact on physical activity, it is important to determine factors that exacerbate or mitigate any decline to inform strategies aiming to prevent further declines in physical activity. This is particularly pertinent given the continued risk of COVID-19[10] and greater likelihood of self-isolating in those with underlying conditions, placing them at increased risk of severe COVID-19.[11]

We are in a unique position to quantify the impact of the COVID-19 restrictions on those with type 2 diabetes, through our existing large comprehensively phenotyped cohort.[12] We aimed to quantify the change in device-measured physical activity before and during the major COVID-19 restrictions in the UK. Second, we aimed to identify key predictors of change in physical activity levels. Potential predictor variables included demographics, health status and physical function.

2 | METHODS

Participants were from the cross-sectional observational study Chronotype of Patients with Type 2 Diabetes and Effect on Glycaemic Control (CODEC, Clinical Trial Registry Number: NCT02973412). Participants were recruited from primary and secondary care in the East Midlands UK, had established type 2 diabetes for >6 months, HbA1c ≤86 mmol/mol (10%) and were aged 18–75 years. Exclusion criteria were terminal illness, BMI >45 kg/m^2, HbA1c >86 mmol/mol (10%), use of sedatives or medications for wakefulness and those with a known sleep disorder (except obstructive sleep apnoea). All participants provided written informed consent. Ethical approval was obtained from the local NHS research ethics committee (West Midlands-Black Country Research Ethics Committee (16/WM/0457)).

Data were available for 885 CODEC participants in March 2020. A subsample of 165 CODEC participants who had ≥3 days accelerometer data, collected between 2017 and 2020 provided verbal consent to take part. England was in

full nationwide lockdown from 23rd March 2020 with gradual easing of some restrictions on May 10th 2020, but indoor mixing of households still prohibited. The main relaxing of restrictions, including reopening of the hospitality industry, occurred on July 4th 2020. Our data were collected between 17th May and 12th June 2020.

2.1 | Pre-COVID measures

Pre-COVID measures were taken between 2017 and 2020. These included the following: date of birth, date of assessment, sex (men/women), ethnicity (White, Black and minority ethnic), body mass index (kg/m^2), smoking status, alcohol intake, index of multiple deprivation (postcode was used to estimate socio-economic status [SES]; lower values indicate more deprived, higher values less deprived), medical history [duration of diabetes and number of diabetes medications], occupation, depressive symptoms [Patient Health Questionnaire 9]), physical function (Short Physical Performance Battery) and HbA1c (glycated haemoglobin). These measures have been described previously.[12]

Baseline physical activity outcomes were derived from the GENEActiv accelerometer (ActivInsights Ltd, Cambridgeshire, UK) which participants wore 24 h a day for 8 days on their non-dominant wrist. Monitors were initialised to record accelerations at 100 Hz. Season of measurement was categorised as Spring, Summer, Autumn and Winter.

2.2 | Measures taken during the major COVID-19 restrictions

Participants were asked a series of COVID-19-related questions over the phone. These included whether they were self-isolating, had been advised to self-isolate, had been tested for COVID-19 and, if so, the result. A GENEActiv was subsequently mailed out to each participant.

To prevent transmission of the SARS-CoV-2 virus, GENEActivs were sterilised prior to posting. Participants were provided with a sterilisation kit to clean the device prior to wearing and were instructed over the phone to leave the accelerometer in the envelope for 2 days prior to wearing to minimise risk of infection/spread. A pre-paid envelope was provided to return the materials.

Consistent with baseline measures, participants wore the GENEActiv 24 h a day for 8 days on their non-dominant wrist.

2.3 | Accelerometer processing

Accelerometer files were processed with R-package GGIR version 1.11–0 (http://cran.r-project.org).[13] Signal processing in GGIR includes autocalibration using local gravity as a reference[14]; detection of non-wear; calculation of the average magnitude of dynamic acceleration corrected for gravity (Euclidean Norm minus 1 g, ENMO), averaged over 5 s epochs and expressed in milli-gravitational units (mg). Non-wear was imputed using the default setting. Participants were excluded if post-calibration error >0.01 g (10 mg), <3 days of valid wear (defined as >16 h per day), or if wear data were not present for each 15-minute period of the 24-h cycle. Sleep duration was calculated using automated sleep detection[15] excluding any waking periods in the night.

Daily physical activity outcomes included overall physical activity (mg), moderate-to-vigorous activity (minutes) accrued in 1-minute bouts (>100 mg[16]), time spent inactive (<40 mg, excluding sleep[17,18]), intensity of the most active continuous 10 minutes/day (mg) and most active continuous 30 minutes/day (mg).

Weekly physical activity outcomes included the number of days/week with 30-minute continuous moderate-to-vigorous activity, and with 60-minute continuous moderate-to-vigorous activity. For weekly variables, only participants with seven valid days were included. A continuous 30- (or 60-) minute moderate-to-vigorous activity session is evident when the intensity corresponding with the 25th percentile of the distribution for the 30 (or 60) continuous minutes is >100 mg (e.g. walking), that is, there is an allowance for up to 25% of time to drop below the threshold consistent with standard bout definitions.[19]

2.4 | Statistical analysis

Demographic data, anthropometric data, accelerometer outcomes and answers to COVID-19 questions are presented as mean (standard deviation) for continuous variables, median (interquartile range) for ordinal variables and n (%) for categorical variables. Demographic and anthropometric data are also presented for the remainder of the CODEC cohort (n = 720). Differences between the CODEC cohort and the subsample were assessed using independent t-tests for normally distributed variables (parametric), Mann–Whitney U test for non-normally distributed variables (nonparametric) and chi-square independence tests for categorical variables.

Data for the subsample were examined using two approaches. First, estimated marginal means, adjusted for age, sex, follow-up time and baseline season of measurement, were derived from general linear models, using a repeated measures design. Pairwise comparisons were used to assess the differences in physical activity outcomes and sleep duration pre- and post-COVID.

Second, linear regressions analyses were used to assess associations between each physical activity outcome at follow-up and baseline predictors. Model 1 considered age,

Baseline			
Demographic variables	**Study subsample** $n = 165$	**Remainder of CODEC cohort** $n = 720$	**p for difference**[a]
Age	64.2 ± 8.3	64.0 ± 8.4	0.426
Sex (women)	74 [45]	229 [32]	0.026
Ethnicity (white)	142 [86]	599 [83]	0.396
Current smokers	6 [3.6]	44 [6.1]	0.628
Index of multiple deprivation rank	18183 ± 8713	19141 ± 9650	0.794
Employment status			0.315
Employed	56 [34]	245 [34]	
Retired	93 [56]	411 [57]	
Other	16 [10]	64 [8.9]	
Number of diabetes medications			0.057
0	32 [19]	120 [17]	
1	69 [42]	257 [36]	
2	38 [23]	234 [33]	
3	24 [15]	101 [14]	
4	2 [1.2]	8 [1.1]	
Duration of diabetes (years)	11.4 ± 7.4	10.9 ± 8.1	0.480
Depressive symptoms (Patient Health Questionnaire 9)	2.5 (0, 7)	2.4 (0, 7)	0.745
Alcohol intake (units/week)	1 (0, 8)	1 (0, 9)	0.747
Short physical performance battery	11 (9, 12)	11 (9, 12)	0.402
Anthropometric variables			
Body mass index (kg/m^2)	31.4 ± 5.4	30.9 ± 5.0	0.391
Cardio-metabolic variables			
HbA1c (mmol/mol)	56 ± 12	54 ± 14	0.139
HbA1c (%)	7.2 ± 1.1	7.0 ± 1.3	
Follow-Up			
Follow-up time (days)[b]	438 (253, 760)		
Number with 7 days of valid accelerometer data (pre and post)	133 [80.6]		
COVID specific variables			
Self-isolating	125 [76]		
Received specific advice to self-isolate	31 [19]		

TABLE 1 Participant characteristics for the study subsample (n = 165) and the remainder of the CODEC (Chronotype of Patients with Type 2 Diabetes and Effect on Glycaemic Control) cohort (n = 720).

Data are presented as mean ±standard deviation for continuous data, median (interquartile range) for ordinal data, or n[%] for categorical data

Socio-economic status measured by the index of multiple deprivation (IMD) rank where a rank of 1 indicates the most deprived and a rank of 32,482 the least deprived.

Depressive symptoms (Patient Health questionnaire 9): Depression severity scores of 0–4 indicate none, 5–9 mild, 10–14 moderate, 15–19 moderately severe and 20–27 severe

[a]independent t-tests for normally distributed variables (parametric), Mann–Whitney U test for non-normally distributed variables (nonparametric) and chi-square independence test for categorical variables.

[b]maximum follow-up time =3 years.

TABLE 2 Adjusted means (95%CI) of physical activity and sleep duration at baseline and during COVID-19 restrictions, adjusted for age, sex and follow-up time

Predictor		Baseline	During restrictions	Difference	p
Daily physical activity (n = 165)	Overall physical activity (mg)	22.3 (21.3, 23.2)	20.6 (19.5, 21.7)	−1.7 (−2.4, −1.0)	**<0.001**
	Time spent inactive (min)	734.2 (719.0, 749.5)	756.1 (739.9, 772.3)	21.9 (9.4, 34.3)	**0.001**
	MVPA (min)	22.4 (18.7, 26.1)	21.7 (18.0, 25.4)	−0.7 (−3.2, 1.9)	0.606
	M30—continuous (mg)	100.9 (94.6, 107.2)	105.8 (96.6, 114.9)	4.9 (−3.0, 13.4)	0.237
	M10—continuous (mg)	132.5 (124.2, 140.8)	137.3 (126.1, 148.5)	4.8 (−4.7, 14.8)	0.327
	Sleep duration (min)	452.9 (442.7, 463.2)	459.8 (449.4, 470.3)	6.9 (−2.5, 16.4)	0.150
Weekly physical activity (n = 133)	Days per week with 60-min continuous MVPA	0.24 (0.09, 0.38)	0.44 (0.23, 0.65)	0.20 (0.01, 0.40)	**0.036**
	Days per week with 30-min continuous MVPA	0.65 (0.41, 0.89)	1.00 (0.72, 1.28)	0.35 (0.10, 0.60)	**0.006**

mg, milli-gravitational units; min, minutes; MVPA: moderate-to-vigorous physical activity; M30 continuous, intensity of most active continuous 30 minutes; M10 continuous, intensity of most active continuous 10 minutes; CI, confidence interval; p, significance from general linear models using a repeated measures design (significant difference denoted in bold.

FIGURE 1 Number of days per week with a continuous 30 min (top) or 60 min (bottom) session of MVPA at baseline (before COVID-19) and during COVID-19 restrictions
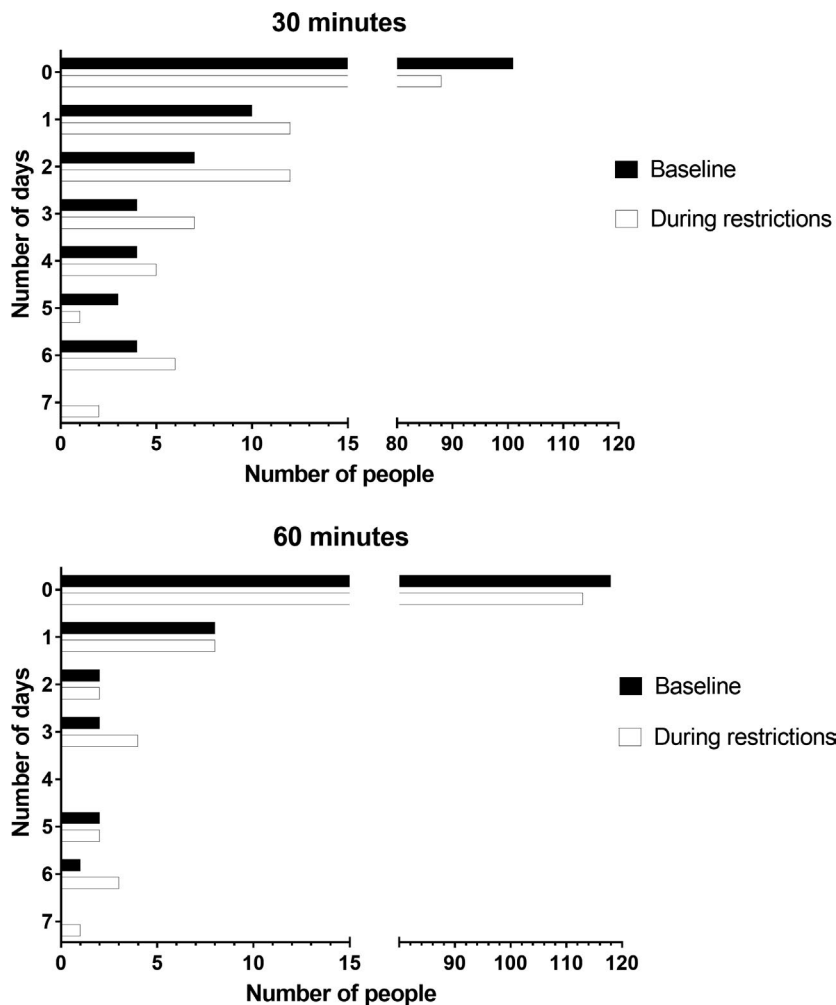
sex, baseline physical activity, season of baseline measurement and follow-up time. In models 2, each of the following predictors was added to model 1 in turn: ethnicity (white, black and minority ethnic), SES, BMI, Patient Health Questionnaire 9, HbA1c, number of diabetes medications, employment status, alcohol intake, smoking status, duration of diabetes, short sleeper (bottom tertile for sleep duration) and physical function. In model 3, predictors from model 1 and significant predictors from models 2 were entered simultaneously.

For daily physical activity outcomes, a normal distribution with an identity link was used. These results are reported as regression coefficients β(95% CI). For weekly outcomes, a Poisson distribution with a log link was used. Data were subsequently back transformed to show the fold change in measures of physical activity per unit change in the predictor. To aid interpretability, the weekly analysis was restricted to those with 7 days of valid pre- and post-data.

A sensitivity analysis was run, removing all individuals who reported being advised to shield. Data were analysed using SPSS (version 26.0). A p value of <0.05 was considered statistically significant. Adjustment was not made for multiple comparisons; therefore, data were viewed with caution and in relation to the overall pattern of results.

3 | RESULTS

There were 165 participants (age (mean±S.D = 64.2 ± 8.3 years, BMI=31.4 ± 5.4 kg/m², 45% women, 86% white) with valid accelerometer data at both time-points for daily physical activity outcomes (three valid days) and 133 participants for weekly physical activity outcomes (seven valid days). The subsample was representative of the wider CODEC cohort except for a larger proportion of women in the subsample (45% cf. 32%). Pre-COVID measures were taken a median of 1.2 years (maximum 3 years) prior to follow-up measures (Table 1). Of the 165 participants, 125 (76%) reported self-isolating during COVID-19 restrictions, 31 (19%) had received advice to shield (letter/text from doctor or National Health Service) and two (1%) had been tested for COVID (both negative). Participant characteristics are presented in Table 1.

3.1 | Difference in physical activity and sleep during COVID-19 restrictions

Differences in physical activity and sleep duration during restrictions are shown in Table 2 (daily and weekly physical outcomes) and Figure 1 (weekly physical activity outcomes). Overall physical activity was significantly lower ($p < 0.001$) by 1.7 mg (approximately 800 steps/day[20]), with corresponding higher inactive time (21.9 minutes; $p = 0.001$). In contrast, time in moderate-to-vigorous activity, intensity of the most active 10–30 minutes and sleep duration were not statistically significantly different. Furthermore, the number of days per week with continuous 30-minute or 60-minute sessions of moderate-to-vigorous activity were 1.5–1.8 times higher, correspondingly the percentage of people with ≥1 day per week with a continuous session of moderate-to-vigorous activity was higher (24%–34%).

3.2 | Baseline predictors of daily physical activity during COVID-19 restrictions

Baseline predictors of daily physical activity outcomes during COVID-19 restrictions are shown in Table 3 (heatmap) and Table S1. In the fully adjusted model, the baseline value was consistently positively associated with all outcomes. Higher BMI was consistently associated with lower physical activity during restrictions, but higher inactive time. For each unit increase in BMI, there were 2.3 minutes more time spent inactive and 0.6 minutes less moderate-to-vigorous activity. In addition, being a woman was associated with lower overall activity (−2.0 mg, approximating 1000 fewer steps/day[20]), ≃20 minutes more inactive time, and 6 minutes less moderate-to-vigorous activity. Older age was associated with lower intensity activity during the most active 10–30 minutes of the day. Black and minority ethnicity was associated with lower overall activity (−2.3 mg, approximating 1150 fewer steps/day[20]). Finally, each additional unit in physical function (the short physical performance test) was associated with 1.7 minutes more moderate-to-vigorous physical activity.

3.3 | Baseline predictors of weekly physical activity during COVID-19 restrictions

Baseline predictors of weekly physical activity outcomes during COVID-19 restrictions are shown in Table 3 (heatmap) and Table S2. Baseline activity and physical function were consistently positively associated, while older age, being a woman, higher BMI and depressive symptoms were all associated with fewer days per week with 30- and/or 60-minutes continuous moderate-to-vigorous activity.

Associations did not differ when removing participants advised to shield ($n = 31$).

4 | DISCUSSION

In adults with type 2 diabetes overall physical activity was lower during restrictions imposed due to COVID-19; the difference was greater than the minimum clinically meaningful difference in physical activity for inactive people, approximating a decrease of 800 steps per day.[20] This was accompanied by slightly more (22 minutes or ~3%) time spent inactive.

Despite this, sleep and purposeful physical activity, that is, moderate-to-vigorous activity accumulated in 1-minute bouts and the intensity of the most active 10–30 minutes, was maintained. Notably, the number of days/week where participants undertook a 30- to 60-minute continuous session of moderate-to-vigorous activity was higher during lockdown. These findings are consistent with data from Garmin

TABLE 3 Heatmap of associations between follow up physical activity value (during COVID-19 restrictions) and baseline predictors

	Predictor	Daily physical activity (n = 165)					Weekly physical activity (n = 133)	
		Overall physical activity	Time spent inactive	MVPA	M30 – continuous acceleration	M10 – continuous acceleration	Days per week with 60min continuous MVPA	Days per week with 30min continuous MVPA
Model 1	Age	grey	grey	grey	orange	orange	orange	red
	Sex (women)	orange	grey	orange	grey	grey	grey	grey
	Follow-up time	orange	red	grey	grey	grey	grey	grey
	Baseline value	green	red	green	green	green	green	green
	Baseline season (Winter(ref) vs spring)	grey	grey	grey	grey	grey	grey	grey
Models 2	+Ethnicity (BAME)	orange	grey	grey	grey	grey	grey	grey
	+SES	grey	light green	grey	grey	grey	green	light green
	+ BMI	red	grey	grey	grey	grey	grey	grey
	+ Depressive symptoms	grey	grey	grey	orange	orange	red	red
	+ HbA1c	grey	grey	grey	grey	grey	grey	grey
	+ T2DM Medications	grey	grey	grey	grey	grey	orange	red
	+ Employment (retired)	grey	grey	grey	grey	grey	grey	grey
	+ Alcohol intake	grey	grey	grey	grey	grey	grey	grey
	+ Smoker	grey	grey	grey	grey	grey	grey	grey
	+ T2DM duration	grey	grey	orange	grey	grey	grey	orange
	+ Short sleeper	grey	grey	grey	grey	grey	grey	grey
	+ Physical function	grey	grey	light green	grey	grey	green	green
Model 3* (multivariate)	Age	grey	grey	grey	red	red	red	red
	Sex (women)	red	orange	orange	orange	grey	grey	grey
	Follow-up time	orange	grey	grey	grey	grey	grey	grey
	Baseline value	green	red	green	grey	grey	green	green
	Baseline season (Winter(ref) vs spring)	grey	grey	grey	grey	grey	grey	grey
	Ethnicity (BAME)	orange						
	SES							
	BMI	red	red	grey	grey	grey	red	red
	Depressive symptoms				orange	orange		orange
	T2DM Medications						grey	grey
	T2DM duration			light green				
	Physical function			light green			green	green

green	Associated with higher activity or lower time spent inactive (p<0.01)
light green	Associated with higher activity or lower time spent inactive (p<0.05)
grey	No association
orange	Associated with lower activity or more time spent inactive (p<0.05)
red	Associated with lower activity or more time spent inactive (p<0.01)

activity trackers, showing that while total steps/day decreased during the COVID-19 pandemic, purposeful activity (number of workout sessions) increased.[21] It is possible the UK Government's focus on 'permitted' outdoor exercise sessions encouraged people to undertake purposeful bouts of physical activity outside. This is supported by the fact that 62% of adults surveyed by Sport England reported that being active now was more important than pre-COVID.[22] Google Trends also showed an increase in online searches for 'exercise' and 'fitness training' during the initial periods of restrictions in the UK, Australia and the USA.[23]

While there was an overall increase in weekly sessions of moderate-to-vigorous activity, it is worth noting the majority (66%) of participants still recorded zero days per week with 30-minutes continuous moderate-to-vigorous activity. Predictors associated with lower physical activity during lockdown were largely consistent with known correlates of physical activity, for example, being a woman, older and higher BMI.[24,25] This is not surprising but highlights that people who are already at greatest risk incur further risk when restrictions to daily movement are imposed. Compounding this, there is evidence that BMI, age, ethnicity and pre-existing cardiometabolic disease are also risk factors for testing positive for SARS-CoV-2 and incidence of severe COVID-19.[26,27]

The observed decrease of ~8% in overall physical activity is lower than in other samples with chronic disease and apparently similar physical activity levels, that is, the self-reported 35% decrease in adults with type 2 diabetes in Spain[4] and 16% decrease in steps per day in heart failure patients in the Czech Republic.[8] These differences could reflect geographical location, the nature of the restrictions imposed and/or government messaging, but may also reflect differing physical activity measurement methods. Furthermore, the maintenance and increase in measures of continuous purposeful moderate-to-vigorous activity may explain the

smaller decrease in overall physical activity observed in the current study. These findings highlight the importance of not only using device-based measures of physical activity but also considering the pattern of accumulation and intensity of physical activity.

Three-quarters of the sample reported self-isolating despite only 31% being specifically advised to. The majority of people self-isolating reported they did so due to Government advice and/or concerns regarding underlying health conditions. The UK is experiencing a further rapid spread in cases of COVID-19 following the emergence of a more transmissible variant; this has led to heightened restrictions and expedited rollout of COVID-19 vaccines.[28] Given this, people with underlying conditions are likely to continue to self-isolate. Our data suggest this is likely to lead to clinically meaningful declines in physical activity[20] with potential consequences for health. Furthermore, lower initial activity levels and/or poorer health both exacerbate the impact of lockdown on physical activity levels; thus, it is important to develop strategies that can be targeted to maintain or increase activity levels in these vulnerable groups.

A strength of our study is device-based measurement of physical activity before and during the COVID-19 restrictions. This gave insight as to how different aspects of physical activity were affected by the restrictions. Furthermore, as our sample was well phenotyped at baseline we were able to determine predictors of change in physical activity during the restrictions. Together these data inform the strategies needed to maintain or improve physical activity during any future lockdown and identify the people at most need of support. We were unable to assess all CODEC participants during restrictions, but the subsample was representative except for a higher proportion of women. We acknowledge the timing of the baseline measures is a limitation as it was up to 3 years (median: 438 days) before COVID-19 and varied between participants. This increases the risk of change in participants' personal, physical, medical, social and professional situations. Furthermore, it was taken throughout the year, although we adjusted for seasonality in our models. Additionally, measures taken during restrictions were not taken during maximum lockdown, instead occurring following the first minor easing of restrictions on May 10th. However, the UK remained in partial lockdown for the duration of the study and Leicester, where this study took place, remained under maximum restrictions with over 75% of our sample reporting that they were self-isolating. Furthermore, easing of restrictions will have had little impact on our mostly retired sample, as the focus was on encouraging those who could not work from home to return to work.

In conclusion, our results suggest that strategies to maintain physical activity levels during lockdown should be two pronged. First, encouragement to undertake a physical activity session at least once per day. Second, break up time spent inactive and increase incidental activity, for example, break up prolonged sitting with light activity. As well as increasing overall activity, breaking up sitting with light movement breaks has beneficial acute metabolic responses, particularly in people at higher metabolic risk.[29] Furthermore, there are existing work-based programmes available to support people in breaking up sitting time[30] that may be suitable for adaption for home use. Finally, this study has identified that heavier, older, inactive, ethnic minority individuals and/or women with type 2 diabetes are most at risk of declining physical activity during COVID-19 restrictions. While acknowledging that some of these subgroups were small, for example, 14% ($n = 23$) of non-white origin, our data suggest these groups could benefit from targeted support.

CONFLICT OF INTEREST

Prof. Kamlesh Khunti is a member of the independent SAGE group. No other conflicts of interest.

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REFERENCES

1. Colberg SR, Sigal RJ, Yardley JE, et al. Physical activity/exercise and diabetes: A Position Statement of the American Diabetes Association. *Diabetes Care*. 2016;39(11):2065-2079.
2. Sluik D, Buijsse B, Muckelbauer R, et al. Physical activity and mortality in individuals with diabetes mellitus: A Prospective Study and Meta-analysis. *Arch Intern Med*. 2012;172(17):1285-1295.
3. Loprinzi PD. Accelerometer-determined sedentary and physical activity estimates among older adults with diabetes: considerations by demographic and comorbidity characteristics. *J Aging Phys Act*. 2014;22(3):432-440.
4. Maugeri G, Castrogiovanni P, Battaglia G, et al. The impact of physical activity on psychological health during Covid-19

pandemic in Italy. *Heliyon*. 2020;6. https://doi.org/10.1016/j.heliyon.2020.e04315

5. Srivastav A, Sharma N, Samuel AJ. Impact of Coronavirus disease-19 (COVID-19) lockdown on physical activity and energy expenditure among physiotherapy professionals and students using web-based open E-survey sent through WhatsApp, Facebook and Instagram messengers. Clin Epidemiol Glob. *Health*. 2020. https://doi.org/10.1016/j.cegh.2020.07.003

6. Ruiz-Roso MB, Knott-Torcal C, Matilla-Escalante DC, et al. COVID-19 lockdown and changes of the dietary pattern and physical activity habits in a cohort of patients with type 2 diabetes mellitus. *Nutrients*. 2020. https://doi.org/10.3390/nu12082327

7. Shephard RJ. Limits to the measurement of habitual physical activity by questionnaires. *Br J Sports Med*. 2003;37:197-206.

8. Vetrovsky T, Frybova T, Gant I, et al. The detrimental effect of COVID-19 nationwide quarantine on accelerometer-assessed physical activity of heart failure patients. ESC. *Heart Failure*. 2020. https://doi.org/10.1002/ehf2.12916

9. Rowlands AV, Yates T, Edwardson CL, et al. Activity intensity, volume & norms: utility and interpretation of accelerometer metrics. *Med Sci Sports Exerc*. 2019;51:2410-2422.

10. Lacobucci G. Covid-19: Leaders warn of "full blown second surge" as hospital admissions rise. *BMJ*. 2020;371:m3941. https://doi.org/10.1136/bmj.m3941

11. Clark A, Jit M, Warren-Gosh C, et al. Global, regional, and national estimates of the population at increased risk of severe COVID-19 due to underlying health conditions in 2020: a modelling study. *Lancet Glob Health*. 2020;8:e1003-e1017. https://doi.org/10.1016/S2214-109X(20)30264-3

12. Brady EM, Hall AP, Baldry E, et al. Rationale and design of a cross-sectional study to investigate and describe the chronotype of patients with type 2 diabetes and the effect on glycaemic control: the CODEC study. *BMJ Open*. 2019;11;9(11):e027773–2018-027773.

13. Migueles JH, Rowlands AV, Huber F, Sabia S, van Hees V. GGIR: A research community-driven open-source R-package for generating physical activity and sleep outcomes from multi-day raw accelerometer data. *J Meas Phys Behav*. 2019;2:188-196.

14. van Hees VT, Gorzelniak L, Dean Leon EC, et al. Separating movement and gravity components in an acceleration signal and implications for the assessment of human daily physical activity. *PLoS One*. 2013;8:e61691.

15. van Hees VT, Sabia S, Jones SE, et al. Estimating sleep parameters using an accelerometer without sleep diary. *Sci Rep*. 2018;8(12975):018–31266-z.

16. Hildebrand M, Hansen BH, van Hees VT, Ekelund U. Evaluation of raw acceleration sedentary thresholds in children and adults. *Scand J Med Sci Sports*. 2017;27:1814-1823.

17. Hildebrand M, van Hees VT, Hansen BH, Ekelund U. Age group comparability of raw accelerometer output from wrist- and hip-worn monitors. *Med Sci Sports Exerc*. 2014;46:1816-1824.

18. Bakrania K, Yates T, Rowlands AV, et al. Developing and validating intensity-based thresholds on raw accelerometer data for discriminating between sedentary behaviours and light-intensity physical activities: a MAD approach. *PLoS One*. 2016;11(10):e0164045.

19. Troiano RP, Berrigan D, Dodd KW, Mâsse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sport Exerc*. 2008;40:181-188.

20. Rowlands AV, Davies MJ, Dempsey PC, Edwardson CL, Razieh C, Yates T. Wrist-worn accelerometers: Recommending ~1.0 mg as the minimum clinically important difference (MCID) in daily average acceleration for inactive adults. Brit. *J Sports Med*. 2020. https://doi.org/10.1136/bjsports-2020-102293

21. Stables J. Garmin data reveals how the world is working out during the lockdown. 2020. https://www.wareable.com/garmin/garmin-data-lockdown-7940. Accessed 27 Aug 2020.

22. England S. *New exercise habits forming during coronavirus crisis*. London, UK: Sport England; 2020.

23. Ding D, Cruz BP, Green MA, Bauman A. Is the COVID-19 lockdown nudging people to be more active: a big data analysis. Brit. *J Sports Med*. 2020. https://doi.org/10.1136/bjsports-2020-102575

24. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJF, Martin BW. Correlates of physical activity: why are some people physically active and others not? *Lancet*. 2012;380:258-271.

25. Biddle G, Edwardson CL, Rowlands AV, et al. Differences in objectively measured physical activity and sedentary behaviour between White Europeans and South Asians recruited from primary care: Cross-sectional analysis of the PROPELS trial. *BMC Public Health*. 2019;19(1):95. https://doi.org/10.1186/s12889-018-6341-5

26. Yates T, Razieh C, Zaccardi F, Davies MJ, Khunti K. Obesity and risk of COVID-19: analysis of UK Biobank. *Prim. Care Diabetes*. 2020. https://doi.org/10.1016/j.pcd.2020.05.0117

27. SAHF. COVID-19 in Black, Asian and Minority Ethnic populations: An evidence review and recommendations from the. *South Asian Health Foundation*. 2020. 978-0-9546712-3-5.

28. Mahase E. Covid-19: Expedite vaccination or deaths will surge, researchers warn. *BMJ*. 2020;371:m4958. https://doi.org/10.1136/bmj.m4958 (Published 29 December 2020).

29. Henson CL, Edwardson CL, Celis-Morales CA, et al. Predictors of the acute postprandial response to breaking up prolonged sitting. *Med Sci Sports Exerc*. 2020;52:1385-1393.

30. Edwardson CL, Yates T, Biddle SJH, et al. Effectiveness of the Stand More AT (SMArT) Work intervention: cluster randomised controlled trial. *BMJ*. 2018;363:k3870. https://doi.org/10.1136/bmj.k3870

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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