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Prospective changes in physical activity, sedentary time and sleep during the COVID-19 pandemic in a US-based cohort study

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ABSTRACT

Objectives Assess differences in movement behaviours within the 24-hour cycle, including light intensity physical activity (LPA), moderate-to-vigorous physical activity (MVPA), sedentary time and sleep, before and during the COVID-19 pandemic and assess these differences stratified by several relevant factors in a subcohort of the Cancer Prevention Study-3.

Design and setting US-based longitudinal cohort study (2018–August 2020).

Participants N=1992 participants, of which 1304 (65.5%) are women, and 1512 (75.9%) are non-Latino white, with a mean age 57.0 (9.8) years.

Measures Age, sex, race/ethnicity, education; self-reported LPA, MVPA, sedentary time and sleep duration collected before and during the pandemic; pandemic-related changes in work, childcare and living arrangement; COVID-19 health history.

Results Compared to 2018, participants spent an additional 104 min/day sedentary, 61 fewer min/day in LPA and 43 fewer min/day in MVPA during the pandemic. Time spent sleeping was similar at the two time points. Differences in movement behaviours were more pronounced among men, those with a higher level of education, and those who were more active before the pandemic.

Conclusions From 2018 to Summer 2020, during the COVID-19 pandemic, US adults have made significant shifts in daily time spent in LPA, MVPA and sedentary. There is an urgent need to promote more physical activity and less sedentary time during this public health crisis to avoid sustaining these patterns long-term.

INTRODUCTION

To halt the spread of the coronavirus disease 2019 (COVID-19), a range of mitigation efforts were implemented, such as prohibiting large gatherings, reducing of face-to-face contact and limiting indoor activities with others. Many workplaces, schools, daycares, restaurants, gyms/fitness centres and other businesses closed, shifted online or drastically altered operations.[1] While these preventative

Strengths and limitations of this study

► Using a prospective, 24-hour paradigm that integrates physical activity, sedentary time and sleep, this study adds to the largely cross-sectional literature investigating the effects of the COVID-19 pandemic on daily behaviours.

► This study further investigates differences between subgroups whose activities may have been differently affected by the pandemic, such as men compared with women, or participants who shifted to remote work compared with those who did not.

► Reliance on self-reported data is a limitation of the current study, although physical activity, sedentary and sleep time survey data were correlated with accelerometry and diary data in previous validation studies.

► The participants in the subcohort were predominately college educated and more physically active before the pandemic than the US population, and thus are not nationally representative.

measures aimed to decrease the spread of COVID-19, these efforts may have inadvertently affected daily movement behaviours within the 24-hour cycle, including different intensities of physical activity (PA), sedentary time and sleep,[2–4] all of which are widely recognised as important risk factors for cardiovascular disease, cancer and premature mortality.[5–9]

Studies report decreases in moderate-to-vigorous intensity PA (MVPA) during the COVID-19 pandemic among adults in Canada,[10] China,[11] France,[12] Jordan,[13] Scotland,[14] Spain,[15] Switzerland,[16] the UK[17 18] and the USA.[19] However, all but a few of these studies[11 12 18] have been cross-sectional, relying on retrospective reports of activity levels before the pandemic, an approach risking recall bias. Additionally, few studies have investigated pandemic-related changes

in sedentary time, a behaviour distinct from inactivity that includes any waking behaviour characterised by a low energy expenditure while sitting or reclining.[20] There are, however, a few studies that suggest that screen time[13] and total sedentary time[16] have increased during the COVID-19 pandemic. Unlike MVPA and sedentary time, results from studies of the association between COVID-19 and changes in sleep, however, are more heterogeneous. Some suggest that the pandemic is associated with an increase in sleep time,[21–24] but a decrease in sleep quality.[25 26] The effect of the pandemic on sleep time may vary with pre-pandemic sleep patterns and mental health status.[27 28]

Although research on PA behaviours during the COVID-19 pandemic has been identified as an urgent public health issue,[29] there remains a need for longitudinal data (including data collected before the pandemic began to minimise recall bias) that simultaneously considers time spent in all the co-dependent daily movement behaviours: PA, sedentary time and sleep. Previous studies investigated one aspect of movement at a time (eg, just MVPA), but no longitudinal study has investigated the impact of the pandemic on these movement behaviours simultaneously; therefore, it is unclear which activities are replacing those that have decreased during the pandemic (eg, if the noted decreases in MVPA have been replaced with lighter intensity activities (LPA), sedentary time or sleep). This information is important for understanding the potential consequences of pandemic-related changes in activity and for crafting effective public health messaging and intervention design. Thus, the aims of this study were: first, to assess the differences in 24-hour movement behaviours (MVPA, LPA, sedentary time and sleep) before and during the COVID-19 pandemic and, second, to assess these differences stratified by several relevant factors (including age group, sex, history of COVID-19 infection, education, household income, living arrangement, pre-pandemic levels of MVPA and pandemic-related changes in work status and childcare, and body mass index) in a subcohort of the Cancer Prevention Study-3 (CPS-3) with prospective data collected before and during the COVID-19 pandemic.

METHODS
Study population and design
The CPS-3 is a prospective study of cancer incidence and mortality initiated by the American Cancer Society in 2006.[30] Over 303 000 participants aged 30–65 years with no history of cancer (except for basal or squamous cell skin cancer) were enrolled across the USA at various community locations between 2006 and 2013. CPS-3 participants completed a detailed lifestyle and medical history survey at enrolment and have completed additional surveys every 3 years beginning in 2015.

In June 2020, an online participant portal was developed and tested in a subgroup of CPS-3 participants. To achieve the desired goal of registering 3000 CPS-3 participants for the portal testing, 13 052 participants who completed the most recent (2018) CPS-3 survey were sent an email invitation to join, and the first 3000 participants to respond were granted access to register for the portal. Among those who registered (n=2979), 2429 participants completed a COVID-19-focused questionnaire (referred to as the COVID-19 survey; 81.5% survey response rate), which sought to determine how the pandemic has affected participants' movement behaviours, physical and mental health, diet, healthcare access, health insurance, employment status and financial security. During this time (July and August of 2020), most cities and/or states across the USA had restrictions on indoor activities (including limited indoor dining and temporary closures of fitness centres and theatres), limitations on the number of people attending public gatherings and mask mandates; unlike other parts of the world, the USA did not experience any night-time curfews or nationwide lockdowns.

Participants were excluded from the analysis for missing or incomplete data on any of the movement behaviours from the 2018 (n=397) or the COVID-19 surveys (n=40). This left a total of 1992 participants in the current study.

Patient and public involvement
There was no patient involvement in this study.

Measures
Participants completed a validated 24-hour movement behaviours survey on both the 2018 and COVID-19 questionnaires.[31–33] For the 2018 survey, participants were asked, 'During the past year, estimate the hours per day you spent on typical weekdays and weekends in each of the following activities. Please average your seasonal physical activities over the entire year. Account for all 24 hours per day'. On the COVID-19 survey, participants were asked the same question with a modified recall period: 'Since the COVID-19 pandemic started…'. Both surveys included, 'sitting or lying down while watching TV' and 'other sitting (at work, at computer, while driving, eating, etc)', which were used to capture total sedentary time; 'standing or moving about', 'walking less than 3 mph or slower than 20 min per mile' and 'light activities' to capture total LPA; 'walking 3 or more mph or faster than 20 min per mile', 'moderate activities' and 'strenuous activities' to capture total MVPA; 'weight training' and 'other resistance exercises' to capture total strength training; and 'sleep' to capture sleep duration. Item responses were all '0, <1, 1–2, 3–4, 5–6, 7–8, 9–10, 11+ hours per day' and the mean number of hours within the response categories (ie, 0, 0.5, 1.5, 3.5, 5.5, 7.5, 9.5, 11 hours per day) were summed to obtain daily average time in each movement behaviour category.

Demographic information, including sex, race/ethnicity (from the baseline questionnaire), household income (2018) and highest level of formal educational attainment (baseline) was collected from previous CPS-3 questionnaires. On the COVID-19 survey, participants were asked about pandemic-related shifts to working

from home, furloughs or job losses, living arrangements, personal COVID-19 history, caregiving responsibilities and childcare disruption.

Statistical analysis

We used a compositional framework to assess movement behaviour changes during the pandemic.[2–4] The compositional framework highlights that PA, sedentary time and sleep are mutually exclusive yet interrelated activities that comprise the entire 24-hour day, and therefore, time spent in each one of these behaviours is dependent on time spent in the others.[2–4] By using this framework, this study simultaneously considers the full 24-hour cycle, including time spent in all movement behaviours.

Average daily LPA, MVPA, strength training, sedentary and sleep time were treated as co-dependent, compositional variables for all analyses. To accomplish this, movement behaviours were first transformed to represent ratios of parts using an isometric log-ratio (*ilr*) coordinate system.[34] After *ilr* transformations are applied, the data can then be analysed using any standard statistical technique that is valid under the assumptions applying to data in real space.[2 3]

The daily composition of time spent in LPA, MVPA, strength training, sedentary and sleeping in 2018 and during COVID-19 (July–August 2020) was described by the geometric mean of time spent in each respective movement behaviour, linearly adjusted so that total daily time spent in movement behaviours summed up to 1440 min/ day (or 24 hours/day). All movement behaviours are expressed in figures as the proportion of the day spent on each movement behaviour. A Wald χ^2 analysis of variance type II test was used to determine if the composition of movement behaviours was significantly different during the COVID-19 pandemic compared with 2018.

Additionally, models were stratified by sex, age group (<50, 50–60, 60–<70, ≥70 years), living arrangement (alone, with others), pre-pandemic activity levels (meet, do not meet US aerobic PA guidelines (150 min/week moderate intensity PA or 75 min/week vigorous intensity PA, or some equivalent combination of the two intensities) in 2018),[35] self-reported COVID-19 history (had, did not have COVID-19), highest level of educational attainment (less than 4-year college degree, college degree or more), pre-pandemic household income (<US$100 000, ≥US$100 000), pandemic-related changes in childcare (disruptions in childcare, not a child caregiver, no change in child care), change in work status (worked remotely, laid off/furloughed, both furloughed and worked remotely and no change) and body mass index (BMI; normal, overweight/obese). Multivariate analysis of covariance models were used to determine the significance of strata group by time (2018 vs during COVID-19) interactions.

Models were adjusted for (1) age and sex, and (2) age, sex, living arrangement (alone, with others), caregiving status (caregiver to adults or children, not a caregiver), employment status (full-time/part-time, retired, other),

highest level of educational attainment (less than 4-year college degree, college degree or more), self-reported COVID-19 history (had, did not have COVID-19), pandemic-related changes in childcare (disruptions in childcare, not a child caregiver, no change in childcare) and change in work status (worked remotely, laid off/ furloughed, both furloughed and worked remotely and no change). As model results (ie, F test statistics, model p values and time interaction p values) were very similar, results from the most parsimonious models are presented and results from fully adjusted models are included in the supplemental materials. All analyses were conducted in R (V.4.0.2) using the 'Compositions' package.[36]

RESULTS

Participants (n=1992, mean age 57.0 (SD: 9.8 years), 65.5% women) were predominantly non-Latino white (75.9%) and highly educated (78.0% with a college degree; table 1). Approximately half (52.5%) of participants met US aerobic PA guidelines prior to the COVID-19 pandemic (2018). Among the participants who met guidelines in 2018, only 43.3% remained active (ie, continued to meet guidelines) during the pandemic (online supplemental table 1). Both before and during the pandemic, approximately 36% of participants' MVPA time was comprised of brisk walking (3 or more mph or faster than 20 min per mile; online supplemental table 2).

Overall changes in movement behaviours

The proportion of daily time spent in specific movement behaviours was statistically significantly different between 2018 and the summer of 2020 (F=87.36, p<0.0001; figure 1 and online supplemental table 3). Compared to 2018, participants spent an additional 104 min/day (7.2% of the day) sedentary, 61 fewer min/day (4.2% of the day) in LPA and 43 fewer min/ day (3.0%) in MVPA during the COVID-19 pandemic. Although time spent strength training was minimal at both time points, the relative time spent strength training was significantly lower during the COVID-19 pandemic (online supplemental figure 1). Daily time spent sleeping was largely similar between the two time points.

Differences by sex

Changes in movement behaviours between the two time points were different among men and women (p-interaction by sex=0.024, figure 2A). In 2018, men spent more time in MVPA (7.4% of the day, or 107 min/day) than women (3.1% of the day, or 45 min/day). There was a larger decrease in MVPA during the pandemic for men compared with women (men: −66 min/day, women: −35 min/day). PA time lost from 2018 to the pandemic was reallocated to sedentary time for both men and women, resulting in an additional 130 min/ day (an additional 9% of the day) and 92 min/day (an

Table 1 Descriptive characteristics of the CPS-3 subcohort, n=1992

	N (%)
Sex	
Women	1304 (65.5)
Men	688 (34.5)
Age group	
<50 years	498 (25.0)
50–<60 years	609 (30.6)
60–<70 years	706 (35.4)
>70 years	179 (9.0)
BMI group	
Normal weight	821 (41.2)
Overweight	632 (31.7)
Obese	539 (27.1)
Race/ethnicity	
Non-Latino white	1512 (75.9)
Non-Latino black	69 (3.5)
Latino	253 (12.7)
Other	158 (7.9)
Pre-pandemic activity level (2018)	
Met MVPA guidelines	1046 (52.5)
Did not meet MVPA guidelines	946 (47.5)
Education	
<4-year college degree	439 (22.0)
College degree or more	1553 (78.0)
Household income (2018)	
<US$50 000	200 (10.0)
US$50 000 to US$99 999	588 (29.5)
US$100 000 to US$149 999	562 (28.2)
≥US$150 000	642 (32.2)
Had COVID-19 (self-report)	212 (10.6)
Live alone	243 (12.2)
Altered caregiving responsibilities	
Disrupted childcare	338 (17.0)
No change in childcare	68 (3.4)
Not a child caregiver	1586 (79.6)
Change in work status	
Laid off/furloughed	110 (5.5)
Worked remotely	930 (46.7)
Worked remote +laid off	73 (3.7)
No change in work status	879 (44.1)

BMI, body mass index; CPS-3, Cancer Prevention Study-3; MVPA, moderate-to-vigorous intensity aerobic physical activity.
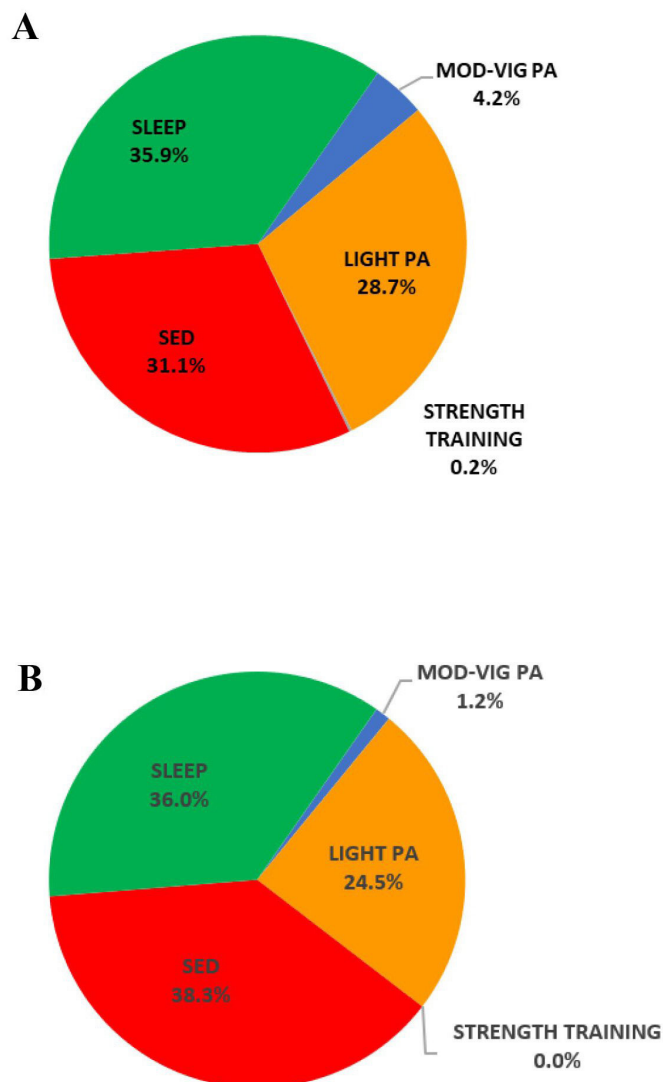
Figure 1 Proportion of time per day spent in each movement behaviour in (A) 2018 and (B) Summer 2020 (the COVID-19 survey). P-difference in 24-hour time-use between the two time points <0.0001. MOD-VIG, moderate-to-vigorous; PA, physical activity; SED, sedentary.

additional 6.4% of the day) of sedentary time for men and women, respectively.

Differences by highest educational attainment and household income

Those with a college degree were more active prior to the pandemic (5.1% of the day, or 73 min/day) and had larger decreases in MVPA during the pandemic (−53 min/day) than those with less than a college degree (2.3% of the day, or 33 min/day of MVPA in 2018; −26 min/day MVPA; p-interaction by education=0.014; figure 2B). Both education groups also experienced large increases in sedentary time during the pandemic for (an additional 112 min/day for those with higher education and 76 min/day for those with lower education). Differences by pre-pandemic household income followed a very similar pattern (p-interaction by income=0.043; data not shown).
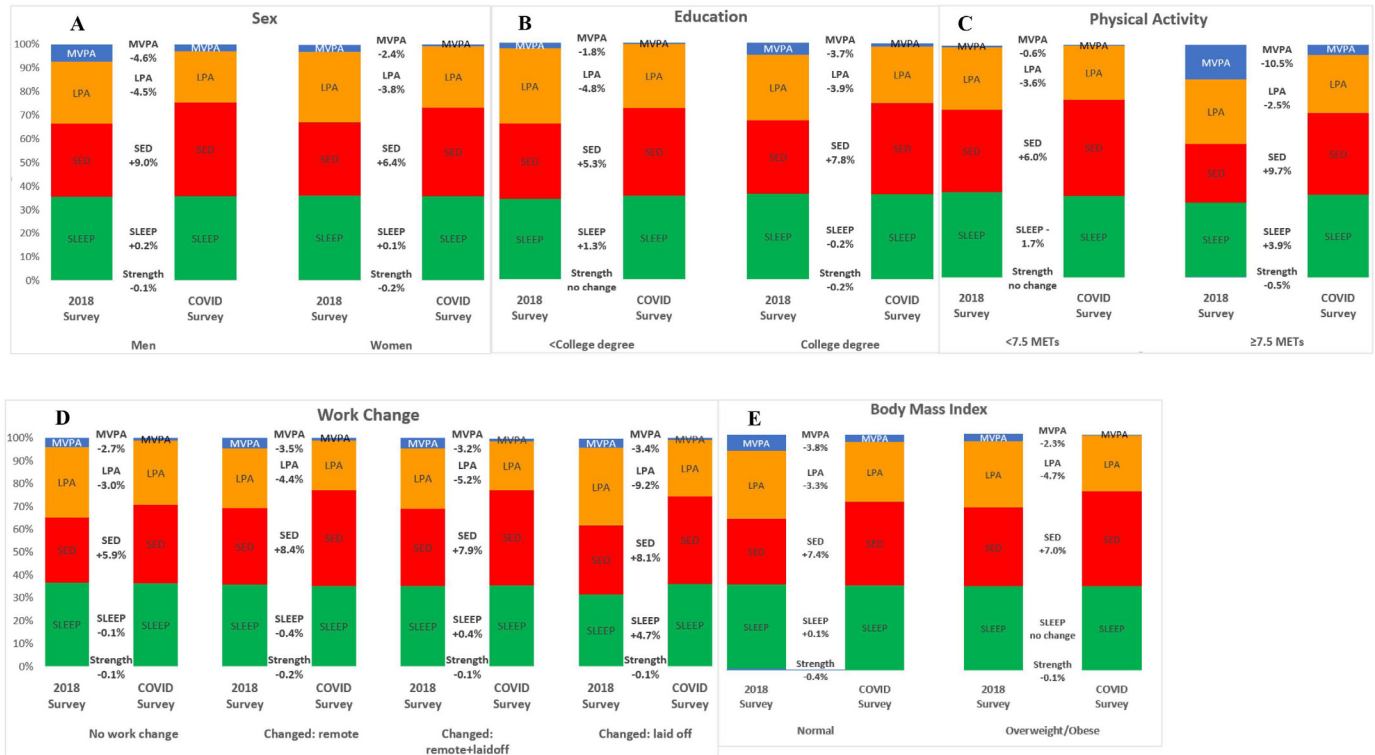
Figure 2 Proportion of time per day spent in each movement behaviour in 2018 and Summer 2020 (the COVID-19 survey) by (A) sex, (B) level of education, (C) 2018 physical activity level, (D) COVID-related change in work status and (E) body mass index category. LPA, light intensity physical activity; MVPA, moderate-to-vigorous physical activity; SED, sedentary; MET, metabolic equivalent hours/week.

Differences by pre-pandemic activity levels

Participants who met aerobic PA guidelines in 2018 experienced larger decreases in the proportion of time spent in MVPA compared with those who did not meet guidelines before the pandemic (−151 min/day vs −9 min/day; p-interaction=0.0009, figure 2C). Some of the time both activity groups spent on MVPA in 2018 was reallocated to sedentary time during the pandemic; however, those who were active before the pandemic also spent a larger proportion of time sleeping during the pandemic compared with 2018 (an additional 56 min/day). There was no difference in sleep time before and during the pandemic among those who were inactive in 2018.

Differences by change in work status

Changes in movement patterns were largely similar among those with a change in work status, although those who were laid off during the pandemic increased sleep duration (an additional 68 min/day), whereas other groups largely maintained consistent sleep time between the two time points (p-interaction=0.039, figure 2D).

Differences by BMI

Differences in movement patterns were largely similar by broad BMI category. However, participants with a normal BMI had a larger decrease in the proportion of time in MVPA compared with participants with overweight or obesity (−54 min/day vs −33 min/day; p-interaction <0.0001, figure 2E).

Other stratified results

Differences in movement behaviours between the two time points were similar among participants of all age groups (p-interaction=0.071) and among participants with different living arrangements (p-interaction=0.267), COVID-19 history (p-interaction=0.476) and childcare responsibilities (p-interaction=0.807).

DISCUSSION

Using data from a prospective national cohort, results from this study suggest that US adults decreased daily light and MVPA, and increased sedentary time from 2018 to Summer 2020, during the COVID-19 pandemic. The changes in time spent on various movement behaviours at the two time points were even more pronounced among men, those with a higher level of education, and those who were meeting PA guidelines before the pandemic. Even those with no notable pandemic-related changes in work (eg, did not shift to remote work, were not laid off or furloughed or were retired prior to the pandemic) still spent nearly 1.5 additional hours/day sedentary—time that had been spent on LPA and MVPA before the pandemic. Additional research will not only benefit people during the remainder of the COVID-19 pandemic but may also be applicable for any potential future pandemics, natural disasters or similar events that disrupt daily life.

Whether or not these unhealthy temporal shifts in movement behaviours will last long-term is unknown. Nevertheless, even short-term changes in movement behaviours may negatively affect mental and physical health. Acute increases in sedentary time and decreases in PA are associated with decreased fat oxidation, increased blood glucose levels, higher resting blood pressure and increased feelings of depression.[37–39] Particularly pressing in the time of an infectious disease pandemic, physical inactivity can downregulate the ability of systems to resist to viral infections, while PA has been shown to increase the efficacy of vaccines.[40 41]

Promoting more PA and less sedentary time during the COVID-19 pandemic brings about a new public health challenge for which there are several feasible solutions. In the current study, while total walking time decreased during the pandemic, the proportion of MVPA comprised of brisk walking remained consistent from 2018 to Summer 2020. This may mean that the promotion of walking as a means of exercise may be one practical way to achieve pre-pandemic MVPA time, especially in places where indoor gyms and studios remain closed. Importantly, outdoor walking is an activity that may be done while wearing a facial covering and remaining physically distanced. If outdoor walking is not a feasible option because of neighbourhood walkability or traffic and crime safety, Dwyer *et al* have adapted currently available web-based resources for remaining active at home during the pandemic.[42] However, as demonstrated in the current study, a narrowed focus on MVPA is likely insufficient, as it ignores the importance of less sedentary time and more LPA. There are many approaches for the promotion of decreased sedentary time through increased LPA at home, especially while working from home, such as setting goals and self-monitoring, computer-based prompts, employee incentive programmes and television or social media time control devices.[43 44]

This study is not without limitations. First, participants in the CPS-3 subcohort were predominately college educated and more physically active than the general US population, which may limit generalisability of these results. As we still saw a reduction in the proportion of participants meeting PA guidelines throughout the pandemic in this very active cohort, we might expect to see even fewer continuing to meet guidelines among the general US population. Additionally, this study relied on self-reported activity data, which may be susceptible to social desirability or other biases that may have led to an overestimation of PA and underestimation of sedentary time, biasing results towards the null. It is worth noting that validation studies of the survey used in this study found that this survey produces estimates of LPA, MVPA and sedentary time that are very similar to accelerometry.[31–33] It is also possible that the average increase in sedentary time and decrease in physical activity from 2018 to 2020 seen in this study reflects a trend consistent with ageing, and was not necessarily caused by the pandemic. However, there was a relatively short time period between surveys (2.2 years on average) with an average decrease in MVPA time of 43 min/day from the 2018 to the COVID-19 survey. For context, the average change in reported PA from the 2015 to 2018 CPS-3 surveys in these same participants (average of 2.9 years apart) was +22 min/day. Given the differences in reported PA over a short period of time in the current study, it seems likely that these differences are indeed a reflection of the pandemic. Strengths of this study include the use of prospective data, with data collected before and during the pandemic, and the consideration of the whole day of movement behaviours, which allows for a more comprehensive understanding of shifts in 24-hour time-use.

Moving more and sitting less has numerous documented benefits, making the temporal shifts observed in this study away from PA towards sedentary time during the pandemic very concerning. As Americans were already struggling to meet PA guidelines before the pandemic, there is an urgent need to organise efforts in promoting more PA and less sedentary time during this public health crisis to avoid sustaining these unfavourable shifts in movement behaviours long-term.

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