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# The impact of the Covid-19 crisis on socioeconomic differences in physical activity behavior: Evidence from the Lifelines COVID-19 cohort study

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ABSTRACT

Covid-19 and measures to contain spreading the disease have led to changed physical activity behavior. This study aims to investigate the relationship between socioeconomic status (SES) and changes in the amount of moderate to vigorous physical activity (MVPA) during the Covid-19 crisis. Using the Dutch Lifelines Covid-19 cohort study ($n$ = 17,749), the amount of MVPA was measured at 15 time-points between March and December 2020, and compared with the amount before the Covid19 pandemic. For SES, the population was stratified in three education and income levels. Logistic regression models were used to estimate the odds ratio (OR) and confidence interval (CI) of altered MVPA for low and high SES groups, with the middle SES category as the reference group. A clear socioeconomic gradient in changes in MVPA behavior was observed. Low educated individuals had significantly higher odds (OR = 1.14; CI: 1.03–1.27) of decreasing MVPA, while the high educated had significantly lower odds of decreased MVPA (OR = 0.84, CI: 0.79–0.90). Both low education (OR = 0.87; CI: 0.77–0.98) and low income (OR = 0.85; CI 0.78–0.92) had significantly lower odds to increase MVPA, while high education (OR = 1.21, CI: 1.12–1.30) and high income (OR = 1.17; CI: 1.07–1.28) had significantly higher odds to increase MVPA. Most findings were consistent over the full research period. Socioeconomic inequalities in MVPA have increased during the Covid-19 pandemic, even when Covid-19 containment measures were relaxed. Our findings suggest that future public health policies need to increase efforts to improve physical activity behavior with an even larger focus on low SES groups.

## 1. Introduction

The social distancing measures and lockdowns implemented by many countries around the world to contain the coronavirus disease 2019 (Covid-19) pandemic have led to dramatic changes in physical activity levels (Wilke et al., 2021; Tison et al., 2020a). These changes may vary between different societal groups. The aim of this study is to investigate the association between socioeconomic status and the probability of decreasing or increasing the amount of moderate to vigorous physical activity (MVPA), compared with the amount of MVPA before Covid-19 containing measures were implemented. Using a large population-based panel, this is the first longitudinal study is the first to examine the socioeconomic gradient of changes in MVPA behavior during the Covid-19 pandemic.

Covid-19 is a highly infectious and potentially deadly disease caused by SARS-CoV-2 virus that can lead to severe respiratory distress (Lai et al., 2020). Covid-19 was declared a global pandemic by the World Health Organization on March 11, 2020. To limit the spread of the disease, most national governments implemented social distancing and other measures (Wilder-Smith and Freedman, 2020). Many of these, such as the closure of schools and businesses, as well as bans on social gatherings and sporting events, have severely affected the opportunities to engage in physical activity (Parnell et al., 2020). As a result, MVPA participation levels have shifted. For many populations, a significant decrease in MVPA levels has been observed (Tison et al., 2020b; Martínez-de-Quel et al., 2021).

Physical activity is an important determinant of health. MVPA reduces the risk of obesity, type 2 diabetes mellitus, cardiovascular disease as well as mental illness such as dementia and depression (Pedersen and Saltin, 2015; Reiner et al., 2013; Chekroud et al., 2018). Regular MVPA

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is also associated with longer life expectancy (Reimers et al., 2012) and lower healthcare costs (de Boer et al., 2020).

It is well-established that physical activity exhibits a strong socioeconomic gradient. There are socioeconomic differences in being physically active (Mackenbach et al., 2008; Beenackers et al., 2012). This socioeconomic gradient in MVPA can be partially explained by differences in available resources, such a time and money (Spinney and Millward, 2010), availability and proximity of facilities for sport and exercise (Wicker et al., 2013), a supportive physical environment (Giles-Corti and Donovan, 2002), social capital (Lindström et al., 2001), as well as beliefs about the benefits of MVPA (Wardle and Steptoe, 2003). In turn, socioeconomic differences in MVPA can contribute to disparities in health outcomes (Petrovic et al., 2018). The Covid-19 pandemic coincides with and exacerbates the ongoing global crisis in physical inactivity and sedentary behavior (Hall et al., 2021). Reducing socioeconomic inequalities has been a priority of international health policies aimed at challenging physical inactivity (DiPietro et al., 2020). It is therefore important to understand socioeconomic disparities of the impact of the Covid-19 pandemic and the related government measures on MVPA behavior.

In the Netherlands, the government initiated the first Covid-19 related social-distancing measures on March 12, 2020 (Dutch National Government, 2021). Schools were closed and bans were introduced on, among others, group and indoor sports activities. In June 2020, when the first wave of the pandemic was contained, some of these measures were relaxed. However, in the autumn of 2020, as the pandemic entered a second wave, increasingly tight measures were (re)instated. From October onwards, sports competitions were suspended, and from December 15, the Netherlands went in full lockdown. As a result, many Dutch residents changed their physical activity behavior. While many individuals became less physically active during 2020, others increased their amount of physical activity (National Institute for Public Health and Environment (RIVM), 2021). A full timeline of the relevant Dutch Covid-19 measures is presented in Table A1 in the Appendix.

Using panel data from the Lifelines Covid-19 cohort, we were able to follow individuals over the course of the pandemic across 15 time points from April until December 2020. Our research reveals the socioeconomic groups that have been most vulnerable with regard to changes into MVPA behavior during the Covid-19 pandemic. The outcomes may help policy makers to curb the negative MVPA trends and improve public health.

## 2. Methods

### 2.1. Data

The Lifelines Covid-19 cohort study is a large population-based cohort study in the North of the Netherlands, that was specifically established to investigate the health and societal impacts of Covid-19 (Mc Intyre et al., 2021). Participants were recruited from the general Lifelines prospective cohort study (Scholtens et al., 2015; Mc Intyre et al., 2021). They were asked to fill out detailed online questionnaires about their physical and mental health and experiences on a weekly basis, starting in late March of 2020, and on a bi-weekly basis from June 2020 (Time points are specified in Table A2 of the Appendix) (Mc Intyre et al., 2021). Unfortunately, no data were available for August and September 2020, because the Lifelines Covid-19 questionnaire in these months did not include questions on physical activity.

The baseline MVPA measurement was part of the first (inquiry date 30/3) and the second (7/4) time-point of the Lifelines Covid-19 study. Baseline measurement from the first time-point was added to that of the second time-point to maximize the size of the cohort. Hence, participants retrospectively estimated their baseline MVPA. The participants without baseline MVPA measurement were excluded from the study sample.

Participants with missing or incomplete data on either education or income level (at baseline) as well as the covariates were omitted (see Fig. A1 in the appendix for the flow chart). Respondents aged 25 or below were excluded from the analysis because their final education level might not yet be known. Pregnant women were also dropped since pregnancy could confound with changes in MVPA. The remaining sample consisted of 17,749 individuals.

For baseline MVPA assessment, respondents were asked: 'before the corona crisis, how many minutes of (moderately) intense activity did you do each week (e.g. walking, bicycling or running)?' The answer categories were: 0–50 min, 50–100 min, 100–150 min, 150–180 min, more than 180 min. At the first seven time-points, respondents were asked about the amount of MVPA they did in the previous 7 days. The answer possibilities were the same as for the baseline measurement. From the 8th measurement, the Covid-19 questionnaire was biweekly, with the corresponding question: 'in the last 14 days, how many minutes of (moderately) intense activity did you do?', and answer categories with double the size of the weekly measurements. The dependent variables were constructed by comparing the amount of MVPA with the baseline measurement and categorized as 'decreased', 'equal' or 'increased', for each individual. The incidences of decreased and increased MVPA were the subject of our investigation and formed separate dependent variables in the research models.

In our study, educational attainment and net personal income functioned as indicators of socioeconomic status. For education, respondents were categorized as 'low education' if they had finished no, low or middle secondary, or lower vocational education; 'middle education' for higher secondary education or middle vocational education; and 'high education' for higher vocational education or university. For net personal income, respondents were asked: 'what was your personal net income before the corona crisis?'; with €500-step answer categories. We redistributed these categories to three roughly equal-sized groups. Individuals with a net income of €1500 or below were categorized as the 'low income' group. The 'high income' group consisted of people with a net income of €2500 or higher.

To adjust for confounding, sociodemographic factors sex (male/female) and age (years) were included. Since research shows that major life events (van Houten et al., 2017; O'Donoghue et al., 2018) can impact MVPA behavior, binary indicators for being single and having one or more children aged 12 or below living at home (yes/no) were strongly correlated with changes in MVPA behavior and therefore included in the analysis. Because smoking and MVPA can be strongly related (Audrain-McGovern et al., 2003), smoking (non-smokers/current smokers) was included as a potential confounder. Also the amount of MVPA practiced at baseline was included in the model. For all covariates, only the measurement at baseline was included, since information at other time-points was either unavailable or incomplete.

### 2.2. Analysis

In this study, we estimated the associations between socioeconomic status (education and income), and decreased and increased MVPA. First, we estimated a logistic regression model (Model 1) for whether MVPA had decreased, for each time-point separately. The same model was estimated for whether MVPA had increased. The resulting odds ratios are visualized in graphs showing, for low and high SES categories, the development of the resulting odds ratios for an increase or decrease in MVPA behavior, over the full span of our panel from March to December 2020. Finally, we estimated a random effects (RE) logistic regression model (Model 2) to estimate the socioeconomic gradient in MVPA changes for the complete panel, with a dummy variable for each of the first 14 time-points and the final time-point ($t = 15$) serving as the reference point. In both Model 1 and Model 2, age, sex, baseline MVPA, living alone, having little children living at home and smoking were included as potential confounders. The (econometric) specifications of Model 1 and Model 2 are presented in the Appendix. For each model, the odds ratio (OR) for the SES indicators (with middle category as

reference) and 95% confidence intervals (CIs) are presented. ORs with a *p*-value below 0.05 were identified as statistically significant. For the analysis, Stata 16 was used (Stata Corp. LLC, College Station, Texas, USA).

## 3. Results

The characteristics of the population at the first measurement point (inquiry at 31/3) are presented in Table 1, with breakdowns by education and income levels. At baseline, 61.3% of the included individuals were female and the average age was 58.1 years. One in ten people was low educated, while 38% had completed higher education. Furthermore, 12.5% were living alone, while 10.6% had little children aged 12 or below living at home and 7.3% were current smokers. Low-SES categories included relatively more elderly people, smokers and people performing less than 100 min of MVPA per week. High-SES categories consisted of relatively many males, adults with little children at home and people performing 150 min or more MVPA at baseline. Compared with the full population of the north of the Netherlands, the dataset consists of relatively many females and older persons and relatively few low-educated individuals and persons with a low income.

At the first time-point, 40% of the individuals decreased their amount of MVPA compared to before the pandemic, while 13% increased the amount (see Table A3 in the Appendix). From the second time-point, decreased MVPA was more or less stable around 23%, until the middle of May when it jumped to around 28%. The percentage of people who increased MVPA grew gradually, to stabilize around 27% in the second half of 2020. The differences between SES categories here were relatively small. Over the period of March to December 2020, the incidence of decreased and increased MVPA (Figs. A2 and A3 in the Appendix) did not appear different among the three education types. It is important to realize that these are the outcomes for the whole sample. Because they had a relatively many people in the category with little (<50 min per week) MVPA, the low-SES categories included a relatively larger number of people that were unable to decrease their amount of MVPA. Similarly, the high-SES categories included relatively many people unable to be included in the 'increased MVPA' category.

In Model 1, the association of education or income with changes in MVPA behavior is estimated, for each time-point. Table 2 shows the outcomes of these models for the first ($t = 1$) and last ($t = 15$) time-point. At t = 1, a clear socioeconomic gradient was found for increased MVPA, but less so for decreased MVPA. At t = 15, both high education and low education were associated with significantly lower risk of decreased MVPA and significantly higher risk of increased MVPA, while the opposite is true for low education and low income. However, for low income these findings were not significant.

Fig. 1 shows the odds ratios, with confidence intervals, for each time-point for Model 1 that represent the association of SES with decreased or increased MVPA. For increased MVPA, odds ratios shift around 1 for the first time-points. Over time, the model outcomes shifted to higher ORs of around 1.2 for low education and lower odds of around 0.8 for higher education (Fig. 1a). Both these estimates differed significantly from the middle education group (ORs defined as 1). For income (Fig. 1b), the differences between the groups were small and insignificant.

Fig. 1c shows the odds ratios for increased MVPA. For high education, the ORs were consistently around 1.25. They also differed significantly from the middle education group for all time-points. The low-education group had initially low odds ratios (OR = 0.71 for beginning of April), but these odds ratios steadily increased over the year, only to drop dramatically at the end of the year (from 0.97 early November to 0.83 for the final measurement). Mostly these odds ratios did not differ significantly from the middle education group. For income groups (Fig. 1d), the differences between groups were somewhat smaller but for most time-points the odds ratios for increasing MVPA were significantly higher for high-income groups than for low-income groups.

Table 3 shows the results of the random effects logit models for the full panel (Model 2). The outcomes show that lower education was associated with significantly higher odds for decreased MVPA (OR = 1.14) and a significantly lower probability of increased MVPA (OR = 0.87), compared with middle education. Similarly, individuals with high education had significantly higher odds of increased MVPA (OR = 1.21), while they also had lower odds of decreased MVPA (OR = 0.84). Meanwhile, the differences between income levels for decreasing MVPA were not significant, although their ORs were in the expected directions. Nevertheless, low income was associated with significantly lower odds of increased MVPA (ORs = 0.85) and the high-income group with

**Table 1**
Summary statistics, by SES categories and total (at first measurement).

| | Education | | | Income (net monthly) | | | Total |
|---|---|---|---|---|---|---|---|
| Variable | Low | Middle | High | Low | Middle | High | |
| Observations (N) | 1766 | 9150 | 6833 | 5922 | 7313 | 4514 | 17,749 |
| Sex (% female) | 52.5 | 65.4 | 58.1 | 86.8 | 59.9 | 30.2 | 61.3 |
| Age: Mean (SD)[a] | 63.5 (8.0) | 58.6 (9.7) | 56.1 (10.8) | 60.2 (9.6) | 57.1 (10.6) | 57.2 (9.9) | 58.1 (10.2) |
| *Education: Highest competed level (%)* | | | | | | | |
| Low[b] | 100.0 | | | 16.8 | 8.8 | 2.9 | 9.9 |
| Middle[b] | | 100.0 | | 63.4 | 53.6 | 32.6 | 51.6 |
| High[b] | | | 100.0 | 19.8 | 37.6 | 64.6 | 38.5 |
| *Income: Net monthly personal income (%)* | | | | | | | |
| Low (<€1500) | 56.2 | 41.1 | 17.2 | 100.0 | | | 33.4 |
| Middle (€1500–€2500) | 36.5 | 42.9 | 40.2 | | 100.0 | | 41.2 |
| High (€2500 or higher) | 7.3 | 16.1 | 42.6 | | | 100.0 | 25.4 |
| Living alone (%) | 14.5 | 12.6 | 11.9 | 11.4 | 14.9 | 10.2 | 12.5 |
| Child 0–12 years living at home (%) | 3.6 | 8.5 | 15.2 | 7.1 | 11.6 | 13.6 | 10.6 |
| Current smoker (%) | 10.6 | 8.4 | 5.2 | 7.9 | 7.6 | 6.4 | 7.4 |
| *PA at baseline, in minutes per week (%)* | | | | | | | |
| 0–50 min | 11.5 | 9.2 | 7.0 | 9.0 | 9.0 | 7.3 | 8.6 |
| 50–100 min | 22.9 | 19.0 | 16.1 | 19.1 | 18.1 | 17.4 | 18.3 |
| 100–150 min | 16.3 | 17.1 | 17.9 | 17.8 | 17.2 | 17.1 | 17.4 |
| 150–180 min | 31.5 | 35.9 | 40.6 | 35.7 | 37.1 | 39.7 | 37.3 |
| 180 min or more | 17.8 | 18.8 | 18.4 | 18.4 | 18.7 | 18.4 | 18.5 |

[a] SD = standard deviation;
[b] Respondents were categorized as 'low education' if they had no, lower vocational, or low or middle secondary education as their highest finished education level. Respondents were classified as 'middle education' if they finished higher secondary education or middle vocational education and 'high education' for completing higher vocational education or university.

**Table 2**
Model outcomes of the logistic regressions (Model 1) for decreased MVPA and increased MVPA for education and income, at first and last measurement.

| Variable | Education | | | | | | | | Income | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | First measurement (t = 1) | | | | Last measurement (t = 15) | | | | First measurement (t = 1) | | | | Last measurement (t = 15) | | | |
| | Decreased MVPA | | Increased MVPA | | Decreased MVPA | | Increased MVPA | | Decreased MVPA | | Increased MVPA | | Decreased MVPA | | Increased MVPA | |
| | OR | P-value | OR | P-value | OR | P-value | OR | P-value | OR | P-value | OR | P-value | OR | P-value | OR | P-value |
| Sex | 1.02 | 0.635 | **1.14** | 0.011 | 1.05 | 0.277 | **1.12** | 0.016 | 0.991 | 0.835 | **1.274** | 0.000 | 0.980 | 0.697 | **1.229** | 0.000 |
| Age | **0.92** | 0.000 | **1.07** | 0.002 | 0.97 | 0.114 | 1.01 | 0.726 | **0.921** | 0.000 | **1.061** | 0.006 | 0.976 | 0.201 | 1.001 | 0.951 |
| Age2 | **1.00** | 0.000 | **1.00** | 0.001 | 1.00 | 0.491 | 1.00 | 0.913 | **1.001** | 0.000 | **0.999** | 0.004 | 1.000 | 0.638 | 1.000 | 0.722 |
| *Education* | | | | | | | | | | | | | | | | |
| Low | 0.91 | 0.128 | **0.86** | 0.077 | **1.23** | 0.008 | **0.83** | 0.021 | | | | | | | | |
| Middle | Ref. | | Ref. | | Ref. | | Ref. | | | | | | | | | |
| High | **0.88** | 0.001 | **1.26** | 0.000 | **0.80** | 0.000 | **1.21** | 0.000 | | | | | | | | |
| *Income* | | | | | | | | | | | | | | | | |
| Low | | | | | | | | | 1.062 | 0.180 | **0.852** | 0.008 | 1.046 | 0.411 | 0.911 | 0.100 |
| Middle | | | | | | | | | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. | Ref. |
| High | | | | | | | | | 0.956 | 0.350 | **1.193** | 0.006 | **0.838** | 0.003 | **1.208** | 0.002 |
| Living alone | **1.15** | 0.014 | 0.99 | 0.928 | **1.14** | 0.047 | 0.89 | 0.079 | **1.150** | 0.012 | 0.984 | 0.829 | **1.145** | 0.045 | **0.882** | 0.069 |
| Child | 1.06 | 0.367 | **1.21** | 0.025 | **1.36** | 0.000 | 0.95 | 0.517 | 1.054 | 0.438 | **1.231** | 0.014 | **1.339** | 0.000 | 0.956 | 0.604 |
| Smoker | **1.16** | 0.038 | **0.69** | 0.000 | **1.27** | 0.006 | **0.77** | 0.002 | **1.167** | 0.033 | **0.674** | 0.000 | **1.301** | 0.003 | **0.752** | 0.001 |
| *PA at baseline (minutes per week)* | | | | | | | | | | | | | | | | |
| 0–50 | n/a | | **1.18** | 0.017 | n/a | | 0.87 | 0.064 | n.a. | | **1.164** | 0.029 | n/a | n/a | **0.859** | 0.043 |
| 50–100 | **0.82** | 0.000 | **0.83** | 0.001 | **0.76** | 0.000 | **0.81** | 0.000 | **0.827** | 0.001 | **0.820** | 0.001 | **0.772** | 0.001 | **0.802** | 0.000 |
| 100–150 | Ref. | | Ref. | | Ref. | | Ref. | | Ref. | | Ref. | | Ref. | | Ref. | |
| 150–180 | 0.97 | 0.483 | **0.05** | 0.000 | **1.15** | 0.025 | **0.08** | 0.000 | 0.967 | 0.475 | **0.048** | 0.000 | **1.143** | 0.031 | **0.080** | 0.000 |
| >180 | **21.57** | 0.000 | n/a | | **12.67** | 0.000 | n/a | | **21.587** | 0.000 | | | **12.675** | 0.000 | n/a | n/a |
| Constant | **5.83** | 0.000 | **0.06** | 0.000 | 0.93 | 0.884 | 0.76 | 0.624 | **5.073** | 0.000 | **0.076** | 0.000 | 0.760 | 0.604 | 0.899 | 0.852 |

OR = Odds ratio. Significant odds ratios (P<0.05) in bold.

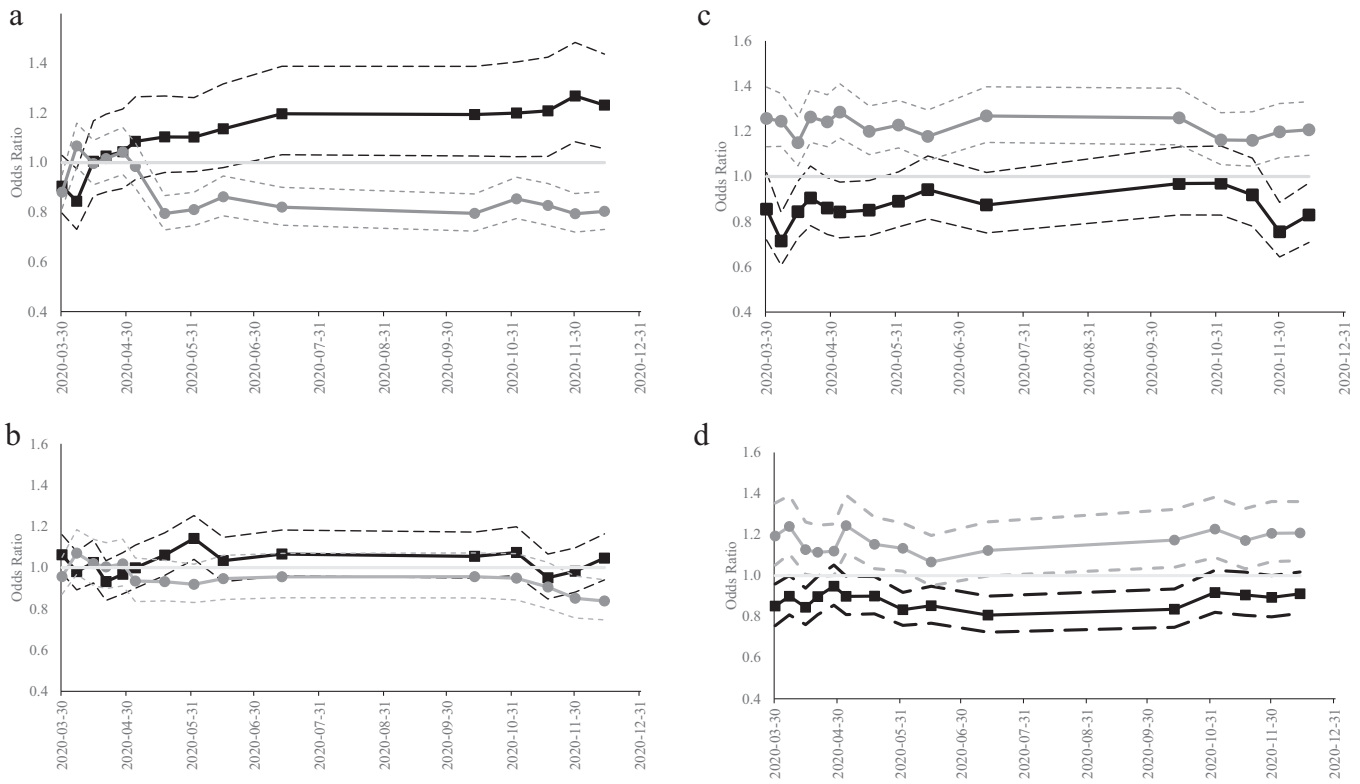


**Fig. 1.** a: Model 1 outcomes for decreased MVPA in odds ratios, by education level. b: Model 1 outcomes for decreased MVPA in odds ratios, by income level. c: Model 1 outcomes for increased MVPA in odds ratios, by education level. d: Model 1 outcomes for increased MVPA in odds ratios, by income level.
Legend: the firm lines with markers show the odds ratios for low education/income (black) and high education (dark grey), with middle education/income (light grey) the reference (OR = 1). The markers are the actual estimated odds ratios for the 15 measurement moments. The dashed lines show the confidence intervals.

**Table 3**
Model outcomes of the RE logistic panel data analysis (Model 2) for decreased MVPA and increased MVPA for education.

| Variable | Education | | | | Income | | | |
|---|---|---|---|---|---|---|---|---|
| | Decreased MVPA | | Increased MVPA | | Decreased MVPA | | Increased MVPA | |
| | OR (CI) | P-value | OR (CI) | P-value | OR (CI) | P-value | OR (CI) | P-value |
| Sex | **1.13** (1.06–1.20) | 0.000 | **1.22** (1.13–1.31) | 0.000 | **1.09** (1.01–1.17) | 0.018 | **1.36** (1.25–1.47) | 0.000 |
| Age | **0.96** (0.93–0.98) | 0.001 | 1.00 (0.97–1.03) | 0.862 | **0.96** (0.94–0.99) | 0.003 | 0.99 (0.96–1.02) | 0.583 |
| Age2 | 1.00 (1.00–1.00) | 0.074 | 1.00 (1.00–1.00) | 0.980 | 1.00 (1.00–1.00) | 0.100 | 1.00 (1.00–1.00) | 0.732 |
| *Education* | | | | | | | | |
| Low | **1.14** (1.03–1.27) | 0.015 | **0.87** (0.77–0.98) | 0.020 | | | | |
| Middle | Ref. | | Ref. | | | | | |
| High | **0.84** (0.79–0.90) | 0.000 | **1.21** (1.12–1.30) | 0.000 | | | | |
| *Income* | | | | | | | | |
| Low | | | | | 1.05 (0.97–1.13) | 0.246 | **0.85** (0.78–0.92) | 0.000 |
| Middle | | | | | Ref. | | Ref. | |
| High | | | | | 0.94 (0.87–1.02) | 0.113 | **1.17** (1.07–1.28) | 0.001 |
| Living alone | **1.23** (1.12–1.35) | 0.000 | 0.94 (0.84–1.04) | 0.223 | **1.23** (1.12–1.35) | 0.000 | 0.93 (0.83–1.03) | 0.159 |
| Child | **1.20** (1.07–1.35) | 0.001 | 1.08 (0.95–1.23) | 0.211 | **1.18** (1.06–1.33) | 0.003 | 1.10 (0.97–1.25) | 0.148 |
| Smoker | **1.39** (1.23–1.57) | 0.000 | **0.64** (0.56–0.73) | 0.000 | **1.42** (1.26–1.60) | 0.000 | **0.63** (0.55–0.72) | 0.000 |
| *PA at baseline (minutes per week)* | | | | | | | | |
| 0–50 | n.a | | **0.66** (0.58–0.74) | 0.000 | n.a | | **0.65** (0.58–0.74) | 0.000 |
| 50–100 | **0.76** (0.69–0.84) | 0.000 | **0.53** (0.48–0.58) | 0.000 | **0.77** (0.70–0.85) | 0.000 | **0.52** (0.47–0.57) | 0.000 |
| 100–150 | Ref. | | Ref. | | Ref. | | Ref. | |
| 150–180 | **1.18** (1.08–1.28) | 0.000 | **0.02** (0.02–0.02) | 0.000 | **1.17** (1.08–1.28) | 0.000 | **0.02** (0.02–0.02) | 0.000 |
| >180 | **32.96** (29.90–36.34) | 0.000 | n.a. | | **33.08** (30.00–36.48) | 0.000 | n.a. | |
| Time dummies | Incl. | | Incl. | | Incl. | | Incl. | |
| Constant | 0.68 (0.33–1.40) | 0.300 | 1.75 (0.77–3.99) | 0.185 | 0.58 (0.29–1.20) | 0.143 | 2.06 (0.91–4.68) | 0.085 |

OR = Odds ratio; CI = 95% confidence interval.

significantly higher odds of increased MVPA (OR = 1.17).

In addition, living alone, living with little children and smoking were associated with significantly higher odds of decreased MVPA. Smoking was associated with significantly lower odds of increasing MVPA, while women had significantly higher odds for both decreasing and increasing than men.

For sensitivity analysis, we estimated Model 2 for males and females and age groups 26–45, 46–60, and 61–75 separately (see Table A6 for the descriptive statistics). The odds ratios for doing decreasing and increasing MVPA were similar between the sexes (Table A7). Hence, the differences between the sexes were small and insignificant. The same was true for the differences in odds ratios between the three age groups (Table A8).

## 4. Discussion

This study is the first to investigate the socioeconomic differences in physical activity behavior during the Covid-19 pandemic over a longer period. Using unique, large, population-based panel data, it was possible not only to document these difference but also follow the trends in the socioeconomic gradient in physical activity behavior over a 9-month period.

We found that, a large proportion of the population decreased their amount of MVPA in the first few weeks after the first Covid-19 measures were introduced. This effect was more or less similar for all socioeconomic groups. However, from May 2020 onwards, a clear socioeconomic gradient emerged, with low-educated individuals having significantly higher odds of decreasing MVPA, than high-educated individuals, ceteris paribus. Also, for increased MVPA, a strong positive socioeconomic gradient was observed. This finding was consistent throughout the whole measurement period. In addition, smoking, living alone or having little children living at home were also factors that significantly increased socioeconomic inequalities in MVPA. The socioeconomic gradient in MVPA *change* that was observed is consistent with the gradient in MVPA *level*, that was found before the Covid-19 pandemic, both in this study many others (Giles-Corti and Donovan, 2002; Wilson et al., 2004).

The model outcomes show that socioeconomic differences are relatively stable over time. In the Summer of 2020, many Covid-19 containment measures were relaxed, but this seems to have had a limited effect on the socioeconomic differences in MVPA behavior that was established during the preceding period with severe measures. In November 2020, when new measures reduced the opportunities to practice sports and physical activities, socioeconomic inequalities in MVPA increased even more. The evidence from this study suggests that in the long run, when the Covid-19 pandemic is contained, socioeconomic inequalities in MVPA levels may remain significantly larger than before theCovid-19 pandemic.

Our analysis has several limitations. First, our study depends on subjective reporting of MVPA instead of more reliable observation measurement methods (e.g. with accelerometers). However, research shows a strong correlation between questionnaire and accelerometer MVPA measurements, especially when time interval levels are used, as was the case in the current study (Hart et al., 2011). Second, for the baseline measurement, respondents were asked about the amount of MVPA they performed “before the Covid-19 crisis”, which lacks specificity. Respondents may have interpreted this question as the amount of MVPA in a specific week or as an average week before the first Covid-19 measures were taken. Also, they could be referring to a week immediately before the corona crisis (March 2020) or for instance the same week exactly a year before the time-point. In all cases, each time-point would include seasonal, as well as weather effects. The lack of clarity is somewhat problematic for both internal consistency of the data and interpretation of the outcomes. Third, MVPA is operationalized as ordinal categories. This means that changes within a category will go unnoticed, while equally small changes across categories (e.g. going from 45 to 55 min MVPA per week) will be reported as MVPA changes. Nevertheless, this issue likely has very limited effect on our results because we have a large sample, from 15 time-points and our results seem very robust to various sensitivity analyses. Fourth, for the lowest (0–50 min./week) and highest (>180 min) baseline MVPA categories, it is only possible to change behavior in one direction. This limits the possibilities and data available for e.g. multinomial logistic regression analysis. Therefore, we have chosen for separate regression analysis for increased and decreased MVPA and use the baseline MVPA categories as controls. Fifth, the study panel was not perfectly representative of the

general population of the northern part of the Netherlands. Although we control for several demographic and socioeconomic variables, this may also be an indication (but not necessarily so) of selection bias in the dependent variables (changes in MVPA). In addition, other factors, such as the respondent's physical or mental health status, were possible confounders of the associations with MVPA, but due to a lack of data we could not control for them. Similar research on Covid-19-related changes in MVPA behavior showed decreased MVPA was relatively more prevalent in the Netherlands (National Institute for Public Health and the Environment, 2021) than in our data, while a study for Flanders study (Constandt et al., 2020) found the opposite. Moreover, the relatively small number of low-SES respondents might lower the predicting power of our analysis. This might be partly due to the online set-up of the survey (e.g. the absence of persons that cannot afford a computer). Sixth, although panel data were used to determine socioeconomic differences in MVPA over time, changes over time in the SES variables and covariates themselves were not measured in the Lifelines Covid-19 survey. Although there might have been changes in, for example, the income levels during the pandemic, we believe this bias would be relatively small because most of the variables that we use cannot change dramatically over a 9-month period and employment and income was protected by the economic measures implemented by the Dutch government. Finally, because our study included only demographic and lifestyle covariates, it is possible that the model estimates suffer from omitted variable bias, such as being infected by the Covid-19 virus. Although this study examines the extend of socioeconomic differences in MVPA behavior, it did not investigate the underlying mechanisms. Future research should look into mediating factors such as psychological, environmental, infrastructural or social aspects, that were known to be important for explaining socioeconomic differences in MVPA behavior before the Covid-19 crisis (Yen and Li, 2019; Brug et al., 2017).

## 5. Conclusion

Before the Covid-19 pandemic, socioeconomic inequalities in physical activity were substantial. This study shows that because of this pandemic and the measures to contain the virus, the gap in MVPA between low- and high-SES groups has widened. The low-SES group was much more likely to decrease MPVA and less likely to increase MVPA during the Covid-19 crisis, compared with higher-SES groups. This gradient is present for both education and income. Alarmingly, our findings show a widening socioeconomic gradient in MVPA that persisted over 9 months, including a period when many Covid-19 containment measures that harm physical activity opportunities were lifted. This means that even after the Covid-19 crisis, the socioeconomic inequalities in MVPA behavior may remain larger than before the pandemic. This suggests that during the current and future pandemics public health policies need to take into account possible effects on physical activity of specific pandemic containment measures. Public health policymakers should be especially very cautious with implementing measures that reduce the opportunities for sports and exercise, because they may harm the physical activity behavior and thus the health in the long run, especially for low-SES groups. Our findings also emphasize the need for public health policies to increase efforts to stimulate physical activity, while taking into account differences across socioeconomic groups. The Covid-19 pandemic may not only coincide with, but also exacerbate, an ongoing global crisis of physical inactivity and sedentary behavior.

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## Patient consent for publication

Not required.

## Ethics approval

The Lifelines study is conducted according to the principles of the Declaration of Helsinki and approved by the Medical Ethics Committee of the University Medical Center Groningen, The Netherlands (2007/152). Before study entry, a signed informed consent form was obtained from each participant.

## Declaration of Competing Interest

The authors declare to have no conflict of interests for this research.

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## Appendix A. Supplementary data

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