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Differential Effects of the COVID-19 Pandemic on Physical Activity Involvements and Exercise Habits in People With and Without Chronic Diseases: A Systematic Review and Meta-analysis

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Abstract

Objective: To conduct a systematic review and meta-analysis to summarize evidence regarding differential changes in physical activity (PA) involvements and exercise habits in people with and without chronic diseases during the COVID-19 outbreak.

Data Sources: MEDLINE, Embase, SPORTDiscus, Cumulative Index to Nursing and Allied Health, PsycINFO, Cochrane Library, and Physiotherapy Evidence Database were searched from November 2019 to May 2021.

Study Selection: Two reviewers independently screened cross-sectional and longitudinal studies that investigated changes in PA-related outcomes in people with and without chronic diseases during the pandemic.

Data Extraction: PA-related outcomes and sedentary time were extracted from the included studies. Relevant risk of bias were assessed. Meta-analyses were conducted for each PA-related outcome, if applicable. Quality of evidence of each PA-related outcome was evaluated by Grading of Recommendations Assessment, Development, and Evaluation.

Data Synthesis: Of 1226 identified citations, 36 articles (28 with and 8 without chronic diseases) with 800,256 participants were included. Moderate evidence from wearable sensors supported a significant reduction in pooled estimates of step count (standardized mean differences [SMD]=−2.79, \( P<.01 \)). Very limited to limited evidence substantiated significant decreases in self-reported PA-related outcomes and significant increases in sedentary behaviors among people with and without chronic diseases. Specifically, pooled estimates of metabolic equivalent-minute per week (SMD=−0.16, \( P=.02 \)) and PA duration (SMD=−0.07, \( P<.01 \)) were significantly decreased, while sedentary time showed significant increases in the general population (small to large effects). Very limited evidence suggested no significant PA changes among people in a country without lockdown.

Conclusions: During the pandemic, objective and self-reported assessments showed significant reductions in PA in people with and without chronic diseases globally. This mainly occurred in countries with lockdowns. Although many countries have adopted the “live with the coronavirus” policy, authorities should implement population-based strategies to revert the potential lockdown-related long-term deleterious effects on people’s health.

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The COVID-19 pandemic posed a menacing threat to global public health. After the first COVID-19 case reported in Wuhan, China, in December 2019,1 the disease has rapidly plagued the globe, inflicting unprecedented negative effects on the global...
Prolonged lockdowns have a negative effect on people’s physical, psychological, and social health. Reduced PA or exercise participation, alongside increased sedentary behaviors, could compromise the physical and mental health of many individuals. The WHO recommends adults to perform 150–300 minutes of moderate intensity or 75–150 minutes of vigorous intensity aerobic PA every week. People with chronic diseases, who are recommended to do regular exercises to delay their disease progression, may be more susceptible to the adverse effect of reduced PA. Reduced PA in these patients not only may affect their disease progression but also increases their risk of developing additional inactivity-related diseases. Regular moderate to vigorous PA (MVPA) can boost immunity against community-acquired infectious diseases and increase potency of vaccination. Although an earlier systematic review has summarized the preliminary effects of the COVID-19 pandemic lockdown on PA changes of the public, it was limited by small representative samples and lack of assessments of evidence or meta-analyses regarding the effects of the pandemic on various PA-related outcomes among people with and without chronic diseases in countries with or without lockdowns. Because PA changes measured by wearable sensors may differ from those collected from self-reported PA questionnaires, comprehensive meta-analyses of various PA-related outcomes can better inform policy makers in developing tailored strategies to revert the adverse effects of physical inactivity in vulnerable subgroups during and after the pandemic. The current systematic review and meta-analysis addressed this gap to summarize the evidence regarding effects of physical inactivity in vulnerable subgroups during and after the COVID-19 pandemic.

Methods

The study protocol was registered on PROSPERO (CRD42021234936). The Preferred Reporting Items of Systematic Reviews and Meta-Analyses guidelines were adopted to report this review.

List of abbreviations:

| Abbreviation | Description |
|--------------|-------------|
| IPAQ         | International Physical Activity Questionnaire |
| MET          | metabolic equivalent task |
| MVPA         | moderate to vigorous physical activity |
| PA           | physical activity |
| SMD          | standardized mean difference |
| T2D          | type 2 diabetes |
| WHO          | World Health Organization |

Search strategy

A systematic literature search was conducted on 7 databases (MEDLINE, EMBASE, SPORTDiscus, Cumulative Index to Nursing and Allied Health, PsycINFO, Cochrane Libraries, Physiotherapy Evidence Database) to identify articles published between November 1, 2019, and May 31, 2021, without any language restrictions. We searched these databases using a combination of 2 sets of keywords: ['COVID' OR 'cov*' OR 'corona*' OR 'severe acute respiratory syndrome coronavirus 2' OR 'SARS*'] AND ['physical activity*' OR 'activity level' OR 'exercise habit*' OR 'exercise routine*' OR 'lifestyle'] (appendix 1). Additional relevant articles were searched from the reference lists of the included studies. Forward citation tracking was conducted using Scopus. The corresponding authors of the included articles were contacted by emails to identify any additional relevant publications.

Selection criteria

Cross-sectional and longitudinal studies that investigated PA-related outcomes during the COVID-19 pandemic were included. Articles were excluded if the participants were actively or previously infected with COVID-19. Commentaries, letters to editors, reviews, conference proceedings, and qualitative studies were also excluded.

Study selection

All citations identified from database searches were exported to EndNote X9 (Clarivate). After removing duplicates, 2 reviewers (K.Y.N., K.H.W.) independently screened the titles and abstracts following the selection criteria. They piloted on 100 abstracts to align discrepancy. They then independently screened the remaining references. Abstracts deemed relevant were included for full-text screening. The process was repeated for the full-text screening. Reviewers met to reach a consensus about the eligible articles. If disagreements persisted, a third reviewer (K.C.K.) arbitrated the disagreements. The interrater agreement was calculated using Cohen's k.

Data extraction

Two independent reviewers (K.Y.N., K.H.W.) used a standardized form to extract data related to authors, year of publication, study location, study design, data collection methods, response and attrition rate, participants’ demographics, definitions of PA and sedentary behaviors, changes in PA-related outcomes, and the corresponding statistics.

Risk of bias assessments

Two independent reviewers (K.Y.N., K.H.W.) used 2 separate tools to assess the quality of the included studies. Specifically, the methodological quality of cross-sectional studies was assessed by the 20-item Appraisal Tool for Cross-Sectional Studies. The tool only provides descriptive assessments without numeric scores. It is flexible for researchers to use it based on their priorities. Therefore, we rearranged the items into 6 domains: objectives and design, study participation, handling of nonrespondents, outcome measures, statistical analysis, and reporting. Similar to our previous reviews, each domain was ranked as low, moderate, or high based on the criteria listed in appendix 2. The Quality in Prognosis Studies tool was used to assess the methodological
quality of longitudinal studies. The Quality in Prognosis Studies tool comprises 6 domains: study participation, study attrition, prognostic factor measurement, outcome measurement, study confounding, and statistical analysis and reporting. Each domain was rated as low, moderate, or high. From the quality of each domain, the overall methodological quality was graded as low, moderate, or high (see appendix 2).

### Data synthesis

PA-related outcomes extracted from the included studies were categorized into 2 pairs of subgroups: (1) the people with and without chronic diseases and (2) countries with and without lockdown. If 2 or more included studies reported changes in a particular PA-related outcome during the pandemic in a given subgroup, the respective standardized mean differences (SMDs) were pooled for a meta-analysis using a random-effects model. All meta-analyses were performed using the Comprehensive Meta-analysis Version 3.3 software. Statistical heterogeneity of the included studies was assessed by $I^2$ statistics and classified as low ($I^2<40\%$), moderate ($I^2=40\%-59\%$), substantial ($I^2=60\%-74\%$), and considerable ($I^2>75\%$) heterogeneity. The potential sources of heterogeneity of each meta-analysis were explained if substantial or considerable statistical heterogeneity was observed.

### Quality of evidence

The quality of evidence of each PA-related outcome was rated by the Grading of Recommendations Assessment, Development, and Evaluation. The Grading of Recommendations Assessment, Development, and Evaluation framework consists of 7 domains, 5 of which could downgrade the quality of evidence regarding the estimated effect size, while the other 2 domains could increase the confidence in the estimated effect size. The synthesized data was ranked as very limited, limited, moderate, or high quality of evidence regarding how the true effect lays close to the estimated effect (see appendix 2).

### Results

The literature search identified 1226 publications, while 13 records were identified through other sources (fig 1). After removing 103 duplicates, 1136 studies were eligible for the title and abstract screening. Of the 95 screened full-text articles, 36 articles were included. Fifty-nine full-text articles were excluded because they did not investigate PA changes (n=40); they included confirmed COVID-19 cases (n=6); or they were commentaries, letters or reviews (n=13).

#### Characteristics of the included studies

The 36 included studies recruited 800,256 participants from Asia, Africa, Australia, Europe, and North and South America. Thirty-five studies were conducted in countries or regions with lockdowns, while a Swedish study was conducted without lockdown. The participants’ mean ages ranged from 7.3-74.0 years. Table 1 summarizes participants’ demographics in the included studies. Twenty-three studies adopted a cross-sectional design, while 13 adopted a retrospective design.

Twenty-eight studies investigated changes in PA in people without chronic diseases. Notably, 20 of them focused on adults, 2 on older people, 4 on students, and 2 on children and adolescents. Eight studies investigated changes in PA among people with chronic diseases. Specifically, 4

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**Fig 1** Flowchart of the systematic review according to Preferred Reporting Items of Systematic Reviews and Meta-Analyses guidelines. Abbreviations: CINAHL, Cumulative Index to Nursing and Allied Health; PEDro, Physiotherapy Evidence Database.
| Author         | Country; Lockdown Policy | Study Sample Characteristics; % Male; Age (y) | Study Population       | Definitions of PA or Exercises | PA-Related Variables | Outcome Measurement Tools (Validation) | Statistical Test |
|----------------|--------------------------|-----------------------------------------------|-------------------------|---------------------------------|----------------------|----------------------------------------|------------------|
| Cross-sectional studies |                          |                                               |                         |                                 |                      |                                        |                  |
| Ammar et al⁶  | Multiple countries; lockdown | N=1047; 46% men; Age: 18-35 y: 55.1%; 36-55 y: 35.1%; >55 y: 9.8% | Healthy adults          | PA as defined by IPAQ*          | IPAQ score           | IPAQ-Short Form (validated)             | Paired t test    |
| Arturo et al⁷ | Mexico; lockdown          | N=37; 59% men; Age: 27.8 ±6.1                 | Healthy adults (Teachers)| PA as defined by IPAQ*          | PA in MET-min/wk      | IPAQ (validated)                        | Student t test   |
| Blom et al⁵⁵ | Sweden; no lockdown       | N=5599; 50% men; Age: 46.3 ±11.0              | Healthy adults          | Daily activity and exercise     | Proportion of participants reported change in PA levels | Customized questionnaire (unvalidated) | Descriptive statistics |
| Chague et al⁹ | France; lockdown          | N=124; 60.5% men; Age: 71.0 ±14.0             | Patients with congestive heart failure | Not defined                    | Proportion of participants reported change in PA levels | Customized questionnaire (unvalidated) | Descriptive statistics |
| Cooper et al¹⁰| United States; lockdown   | N=1607; 43% men; Age: 38.0 ±12.9              | Healthy adults          | Overall PA, walking for at least 30 min/d, PA as defined by IPAQ* | Proportion of participants reported change in PA levels | IPAQ-Short Form (validated) | Descriptive statistics |
| Deng et al¹¹  | Wuhan, China; lockdown    | N=1607; 64.8% men; Age: <18 y: 1.2%; 18-22 y: 97.9%; >22 y: 0.9% | Healthy students (university and college) | Regular exercise as defined as ≥3 times/wk and ≥60 min each time | Proportion of participants reported change in exercise habit | Customized questionnaire (unvalidated) | Descriptive statistics |

(continued on next page)
| Author          | Country; Lockdown Policy | Study Sample Characteristics; % Male; Age (y) | Study Population         | Definitions of PA or Exercises PA-Related Variables | Outcome Measurement Tools (Validation) | Statistical Test |
|-----------------|--------------------------|-----------------------------------------------|--------------------------|-----------------------------------------------------|----------------------------------------|------------------|
| Di Renzo et al.12 | Italy; lockdown          | N=3533; 23.9% men; Age: 40.0 y±13.5           | Healthy adults (internet users) | Sports training eg, walking; gym/run/swimming/soccer/volleyball/basketball/CrossFit/dance/yoga/aerobic fitness/martial arts/tennis/aerial gymnastics | Proportion of participants reported change in exercise habit | Customized questionnaire (unvalidated) | Descriptive statistics |
| Đogaš et al.14  | Croatia; lockdown        | N=3027; 20.3% men; Median age: 40 y           | Healthy adults           | Not defined | Duration of PA | Customized questionnaire (unvalidated) | Paired t test |
| Duncan et al.15 | United States; lockdown  | N=3971; 30.8% men; Age: 50.4 y±16.0           | Healthy adults (identical and same-sex fraternal twins) | Not defined | Proportion of participants reported change in PA levels | Customized questionnaire (unvalidated) | Descriptive statistics |
| Galle et al.17  | Italy; lockdown          | N=2125; 37.2% men; Age: 22.5 y±0.1             | Undergraduate students   | Not defined | Proportion of participants reported change in PA levels | Customized questionnaire (unvalidated) | Descriptive statistics |
| Hu et al.18     | China; lockdown          | N=1033; 51.7% men; Age: 18-30 y: 61.7% 31-40 y: 27.2% >41 y: 11.1% | Healthy adults           | Exercise (such as running and dancing) | Proportion of participants reported change in exercise habit | Proportion of participants reported change in sedentary time | IPAQ (validated) | Descriptive statistics |
| Lehtisalo et al.21 | Finland; lockdown       | N=613; 51.2% men; Age: 67.9 y±4.6             | Older adults             | Leisure time physical activity, housework or cleaning, gardening | Proportion of participants reported change in PA levels | Customized questionnaire (unvalidated) | Descriptive statistics |
| Lesser et al.22 | Canada; lockdown         | N=1098; 19.6% men; Age: 42.0 y±15.0           | Healthy adults           | Walking/jogging/running/biking/cycling/weight training/online video/classes/yoga/home workout/hiking/home/yard work/other | Proportion of participants reported change in PA levels | Behavioral regulations in exercise (validated) | Godin Leisure Questionnaire (validated) | Descriptive statistics |

(continued on next page)
| Author          | Country; Lockdown Policy | Study Sample Characteristics; % Male; Age (y) | Study Population | Definitions of PA or Exercises | PA-Related Variables | Outcome Measurement Tools (Validation) | Statistical Test |
|-----------------|--------------------------|-----------------------------------------------|------------------|---------------------------------|----------------------|----------------------------------------|------------------|
| Minsky et al    | Israel; lockdown         | N=279; 30.8% men; Age: 53.0 y±13.0             | Adults with obesity | Not defined                     | Proportion of participants reported change in PA levels | Customized questionnaire (unvalidated) | Descriptive statistics |
| Orlandi et al   | Italy; lockdown          | N=2218; 34.3% men; Age: 38.2 y±14.9            | Healthy adults   | PA as defined by IPAQ*           | PA in MET-min/wk (converted from PA in MET-h/wk) | IPAQ (validated)          | Paired t test |
| Paltrinieri et al| Italy; lockdown          | N=2816; 23.2% men; Age: 18-44 y: 44.8% 45-64 y: 44.0% >65 y: 10.6% | Healthy adults   | Not defined                     | Proportion of participants reported change in PA levels | Customized questionnaire (unvalidated) | Descriptive statistics |
| Persiani et al  | Italy; lockdown          | N=292; 49% men; Age: <35 y: 10.3% 35-50 y: 23% 50-70 y: 57.2% >70 y: 9.6% | Patients with musculoskeletal pain | Not defined                     | Change in PA levels in participants | Customized questionnaire (unvalidated) | Descriptive statistics |
| Rodriguez-Nogueira et al | Spain; lockdown | N=472; 40% men; Age: 46.4 y±11.2 | Healthy adults | Aerobics, strength exercise, and others | Change in PA levels in participants | Standardized Nordic Questionnaire (validated) | Descriptive statistics |
| Ruiz-Roso et al | Italy; lockdown          | N=726; 39.8% men; Age: 10-15 y: 45.7% 16-19 y: 54.3% | Adolescents     | Active: PA ≥300 min/wk           | Change in PA levels in participants | IPAQ (validated)          | Descriptive statistics |
| Sonza et al     | Brazil and Europe; lockdown | N=3194; 32.9% men; Age: 38.4 y±13.6          | Healthy adults   | Aerobics, resistance and strength exercise | Change in PA levels in participants | Physical exercise level before and during social isolation questionnaire (validated) | Descriptive statistics |
| Stanton et al   | Australia; lockdown      | N=1491; 32.6% men; Age: 50.5 y±14.9            | Healthy adults   | PA as defined by Active Australia Survey | Duration of PA | Active Australian Survey (validated) | Descriptive statistics Wilcoxon signed-rank test |
| Yamada et al    | Japan; lockdown          | N=1600; 50% men; Age: 74.0 y±5.6               | Older adults     | PA as defined by IPAQ*           | Duration of PA | IPAQ-Short Form (validated) | Wilcoxon signed-rank test |
| Zhu et al       | China; lockdown          | N=889; 39% men; Age: 31.9 y±11.4                | Healthy adults   | Step counts                      | Duration of sedentary time | Customized questionnaire (unvalidated) | Paired t test |

(continued on next page)
| Author          | Country; Lockdown Policy | Study Sample Characteristics; % Male; Age (y) | Study Population                          | Definitions of PA or Exercises | PA-Related Variables | Outcome Measurement Tools (Validation) | Statistical Test |
|-----------------|--------------------------|---------------------------------------------|-------------------------------------------|--------------------------------|----------------------|----------------------------------------|------------------|
| Al Fagih et al  | Saudi Arabia; lockdown   | N=82; 64.6% men; Median age: 65 y           | Patients with heart failure               | Defined by algorithms of a cardiac implantable electronic device | Duration of PA       | Cardiac implantable electronic devices | Wilcoxon signed-rank test |
| Barrea et al    | Italy; lockdown           | N=121; 33.5% men; Age: 44.9 y±13.3          | Healthy adults                            | ≥30 min/d of aerobic exercise  | Change in exercise habit in participants | Dichotomous questions (unvalidated) | χ² test |
| Di Sebastiano et al | Canada; lockdown           | N=2338; 9.8% men; Age: 18-65 y: 92% >65 y: 8% | Healthy adults                            | MVPA: defined by a device specific definition, or ≥100 steps/min | Duration of light PA | Duration of MVPA | Step counts | Wearable devices or smartphone inbuilt accelerometer | 1-way repeated-measures ANOVA |
| Dunton et al    | United States; lockdown   | N=211; 47.4% men; Age: 8.7 y±2.6            | Healthy children                          | 11 types of school-based PA enlisted in Active Where survey | Proportion of participants reported change in sedentary time | Active Where survey (validated) | Descriptive statistics |
| Jia et al       | China; lockdown           | N=10,082; 28.3% men; Age: 19.8 y±2.3        | High school, college, and graduate students | PA as defined by IPAQ*            | Duration of MVPA     | IPAQ (validated) | Paired t test |
| Keel et al      | United States; lockdown   | N=90; 12.2% men; Age: 19.45 y±1.3           | Undergraduate students                    | Not defined                  | Duration of sedentary time | Customized questionnaire (unvalidated) | Descriptive statistics |
| Pépin et al     | Multiple countries; lockdown | N=742,200; 62% men; Mean age: 43.4 y          | Healthy adults                            | Step counts                  | Step counts          | Wearable pedometer | Wilcoxon signed-rank test |
| Rowlands et al  | United Kingdom; lockdown  | N=165; 55% men; Age: 64.2 y±8.3             | Patients with T2D                         | Defined by accelerometer     | Duration of MVPA     | Wearable accelerometer | Paired t test |

(continued on next page)
| Author            | Country; Lockdown Policy | Study Sample Characteristics; % Male; Age (y) | Study Population | Definitions of PA or Exercises | PA-Related Variables | Outcome Measurement Tools (Validation) | Statistical Test |
|-------------------|--------------------------|---------------------------------------------|------------------|-------------------------------|----------------------|----------------------------------------|------------------|
| Van Bakel et al   | Netherlands; lockdown    | N=1565; 73.1% men; Age: ≤65 y: 756 >65 y: 677 | Patients with cardiovascular disease | MVPA determined by work, transportation, household, and leisure time | Duration of MVPA | Short Questionnaire to Assess Health-enhancing Physical Activity (validated) | Mann-Whitney U test |
| Vetrovsky et al   | Czech Republic; lockdown | N=26; 69.2% men; Age: 58.8 y±9.8            | Patients with heart failure | Step counts             | Step counts          | Wearable accelerometer                 | Paired t test    |
| Wang et al        | China; lockdown           | N=3544; 65.4% men; Age: 51.6 y±8.9          | Healthy adults    | Step counts             | Step counts          | Smartphone inbuilt accelerometer      | Generalized Estimating Equation Paired t test |
| Weaver et al      | United States; lockdown  | N=362; 47.8% men; Age: 46.5 y±16.0          | Healthy adults    | PA as defined by IPAQ*    | PA in MET-min/wk     | IPAQ-Short Form (validated)            | Paired t test    |
| Zorcec et al      | Macedonia; lockdown      | N=72; 12.5% men; Age: 7.3 y±2.9              | Children with chronic respiratory diseases | Not defined       | Change in PA levels in participants | Customized questionnaire (unvalidated) | Descriptive statistics |

Abbreviation: ANOVA, analysis of variance.  
* Definition of PA according to IPAQ: refer to appendix 3.  
† Definition of PA according to Active Australian Survey: refer to appendix 4.  
‡ Interpretation of acceleration in milligravitation units: refer to appendix 5.
focused on patients with cardiovascular diseases,13,39,33,34 1 on type 2 diabetes (T2D),29 1 on musculoskeletal pain,27 1 on adults with obesity,23 and 1 on children with chronic respiratory diseases.39

**Risk of bias assessments**

One study was rated as having low risk of bias,29,31 as moderate,6-26,28,32,35,56 and 4 as high,5,27,30,31 Of the 23 cross-sectional studies, the most common risks of bias were no sample size justification6,7,9-12,14,15,18,21-25,27,30,32,37,38,56 and no description of nonresponders’ characteristics6,7,9-12,14,15,17,18,21-25,27,28,30,32,37,38,56 (appendix 3). All the 13 retrospective studies did not provide information regarding the dropout participants nor accounted for potential confounders (appendix 4).5,8,13,16,19,20,26,29,33,36,39

**PA and sedentary time**

The included studies used diverse definitions of PA (appendices 5-7, table 2). Five studies used accelerometers and/or pedometers to quantify PA levels.13,26,29,34,35 Eight studies used the International Physical Activity Questionnaire (IPAQ) to categorize PA into different levels.7,10,18,19,24,36,37 Fourteen studies had miscellaneous definitions of PA (eg, regular exercise for different durations or different leisure time PA).5,9,11-13,16,18,21,22,26,30,31,33,36,38 whereas 9 studies did not clearly define PA.9,14,15,17,20,23,25,27,29 For the 12 studies that investigated sedentary behaviors,9,10,16,18,19,27,29,31,33,36,38,56 1 used accelerometers to record sedentary time,9,10,18,19 4 used self-reported screen time,9,10,18,19 and 4 used self-reported sitting and/or couch time.10,16,27,36 However, 3 studies only mentioned sedentary behaviors without definitions.31,33,38

Thirteen PA-related variables were reported in the included studies. Of them, 12 were reported in studies involving people without chronic diseases (appendix 8), while 8 were reported in studies involving people with chronic diseases (appendix 9). Those studies conducted in regions involving lockdowns reported 12 PA-related variables (see appendices 8 and 9), whereas the Swedish study (without lockdown) reported 3 PA-related variables in people without chronic diseases (see appendix 8).

**Quality of evidence regarding changes in PA during the pandemic in people without chronic diseases**

The included studies investigating changes in PA of people without chronic diseases were conducted in countries with39 and without56 lockdowns. These changes in PA-related variables are summarized in fig 2 and table 2.

**Step counts (per d/wk)**

Moderate evidence from 4 studies consistently showed significant decreases in step counts after the outbreak as measured by accelerometers, pedometers, or a self-reported questionnaire.13,26,35,38 The meta-analysis showed a significant reduction in step counts with a large effect size (pooled $SMD=-2.79, P<0.01, I^2=100\%$).

**Durations of light PA and MVPA**

Very limited evidence from 1 Canadian study revealed a significant reduction (12.6%) in the duration of light PA as measured by accelerometers during the pandemic.13 Likewise, very limited evidence from 2 studies suggested reduced durations of MVPA.13,19 Specifically, 1 study used accelerometers to detect significant decreases in the duration of MVPA (9.3%) after the outbreak.13 Another study used IPAQ to reveal a significant reduction in time spent on MVPA after lockdown.19

**Duration of PA**

Very limited evidence substantiated decreases in self-reported weekly PA duration.14,32,37 However, because 1 included study did not present the relevant statistical data,32 it was excluded from the meta-analysis. The meta-analysis showed a significant reduction in PA duration per week with a small effect size (pooled $SMD=-0.07, P<0.01, I^2=0\%$).14,37

**Proportion of participants reporting changes in PA levels**

There was inconsistent evidence regarding the proportion of people reporting changes in PA levels during the outbreak. Five studies used customized questionnaires to evaluate changes in PA during lockdowns, although PA was not defined.15,17,20,21,25 They found that 20.7%-61.5% of participants reported decreases, 13.6%-53.2% reported no change, and 5.3%-48.6% reported increases in PA levels.15,17,20,21,25 Similarly, 3 included studies used validated questionnaires to evaluate changes in PA levels during lockdowns.10,22,23 They showed that 20.7%-33.9% of participants reported decreases, 25.1%-30.5% reported no change, and 35.7%-49.1% reported increases in PA levels.10,22,23 A Swedish study (without lockdown) used a customized questionnaire to reveal that 63.0% of participants reported no change in PA levels, and only 26.0% reported decreases in PA levels during the outbreak.14

**Changes in number of participants involving in different PA categories**

There was very limited evidence supporting the adoption of an inactive lifestyle during lockdowns.26,30,31 Although 3 studies revealed that more people were classified into the low PA category after the outbreak,28,30,31 1 of them reported approximately 30% increase in the number of people being categorized into “never performed PA” or “frequently performed PA” during the COVID-19 outbreak.28

**Proportion of participants reported changes in their exercise duration**

Limited evidence from 2 included studies supported that people living in countries with lockdowns reported either no change or decreases in their exercise duration, while only 17.8%-20.0% of people reported increases in their exercise duration.11,18 Conversely, up to 26% of participants reported increases in exercise in a country without lockdown.56

**Proportion of participants reported doing regular exercise**

There was conflicting evidence regarding the proportion of people participating in regular exercises.8,12 One included study reported no significant changes in the proportion of participants involved in regular exercise training after the outbreak,12 while another study revealed a 19% drop in the number of participants who exercised regularly.8 However, both studies used unvalidated questionnaires.

**Metabolic equivalent-minute per week**

Very limited evidence supported reduced estimated metabolic equivalent task (MET)-minute per week as measured by IPAQ.7,24,36 The PA reduction ranged from 23.8%-69.8%.7,24,36 The meta-analysis from 3 studies showed a significant reduction in MET-minute per week with a small effect size (pooled $SMD=-0.16, P=0.02, I^2=77\%$).7,24,36
## Table 2  Summary of results on PA-related variables in people without chronic diseases

| Countries with lockdown measures | Study Sample Size | Study Population | Definition of PA-Related Outcomes | Statistical Test | Results | Level of Significance | Effect Size | Level of Evidence |
|---------------------------------|------------------|------------------|----------------------------------|------------------|---------|-----------------------|------------|-------------------|
| Step counts (per d or per wk) (N=6) | Di Sebastiano et al 13  | N=2338  | Healthy adults | Step count/wk as measured by wearable devices or a smartphone in-built accelerometer | 1-way repeated-measures ANOVA | Decreased from 48,625±745 steps/wk to 43,395±705 steps/wk (by 10.8%) | P<.001 | Large | Moderate |
|佩林 et al 18  | N=742,200  | Healthy adults | Step count/d as measured by a pedometer | Wilcoxon signed-rank test | Decreased from 5326±479 steps/d to 4752±925 steps/d (by 10.8%) | P<.001 | Not reported | |
| Wang et al 15  | N=3544  | Healthy adults | Step count/d as measured by a smartphone in-built accelerometer | Generalized Estimating Equation | Decreased from 8097±4793 steps/d to 5440±4571 steps/d (by 32.8%) | Not reported | |
| Zhu et al 18  | N=889  | Healthy adults | Step count/day as measured by an unvalidated self-developed questionnaire | Paired t test | Decreased from 6247±4374 steps/d to 2714±3542 steps/d (by 56.6%) | P<.001 | |
| Duration of light PA (N=1) | Di Sebastiano et al 13  | N=2338  | Healthy adults | Light PA as measured by an accelerometer: <100 steps/min | 1-way repeated-measures ANOVA | Decreased from 1000.5±17.0 min/wk to 874.1±15.6 min/wk (by 12.6%) | p<.001 | Very limited | |
| Duration of MVPA (N=2) | Di Sebastiano et al 13  | N=2338  | Healthy adults | MVPA: defined by heart rate ≥60% heart rate maximum by a built-in monitor, or ≥100 steps/min | 1-way repeated-measures ANOVA | Decreased from 194.2±5.2 min/wk to 176.7±5 min/wk (by 9.3%) | P<.001 | Very limited | |
| Jia et al 19  | N=10,082  | High schools, colleges, and graduate schools students | PA as defined by IPAQ* | Paired t test | From 0.7±2.0 d/wk to 0.7±2.0 d/wk | P<.05 | |
| Duration of PA (N=3) | Đoga et al 14  | N=3027  | Healthy adults | Not defined | Paired t test | Decreased from 162.1 min/wk to 132.9 min/wk (by 18%) | P<.001 | Small | Very limited |
| Stanton et al 12  | N=1491  | Healthy adults | PA as defined by Active Australian Survey* | Wilcoxon signed-rank test | Decreased to 312.5±363.5 min/wk | Not reported | |
| Yamada et al 37  | N=1600  | Healthy adults | PA as defined by IPAQ* | Wilcoxon signed-rank test | Decreased from 245 min/wk to 180 min/wk (by 27%) | P<.001 | |
| Proportion of participants reporting changes in PA levels (N=8) | Cooper et al 10  | N=1607  | Healthy adults | PA as defined by IPAQ* | Descriptive statistics | Overall PA: n=413 reported decrease (25.7%) n=404 reported no change (25.1%) n=790 reported increase (49.1%) Low PA level: n=565 reported decrease (35.2%) n=574 reported no change (35.7%) n=468 reported increase (29.2%) Moderate PA level: n=519 reported decrease (32.3%) n=806 reported no change (50.2%) n=282 reported increase (17.6%) High PA level: n=566 reported decrease (35.2%) n=736 reported no change (45.8%) n=306 reported increase (19.0%) | NA | Conflicting | |
| Duncan et al 15  | N=3971  | Healthy adults (identical and same-sex fraternal twins) | Not defined | Descriptive statistics | Overall: n=1048 reported decrease (26.4%) n=1183 reported no change (29.8%) n=1740 reported increase (43.8%) | NA | |
| Galle et al 37  | N=2125  | Undergraduate students | Not defined | Descriptive statistics | Overall: n=640 reported decrease (30.1%) n=1032 reported in increase (48.6%) | NA | |
| Keel et al 32  | N=90  | Undergraduate students | Not defined | Descriptive statistics | Overall: n=413 reported decrease (25.7%) n=404 reported no change (25.1%) n=790 reported increase (49.1%) | NA | |

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| Author                        | Study Sample Size | Study Population                  | Definition of PA-Related Outcomes                                                                                                                                                                                                 | Statistical Test          | Results                                                                                           | Level of Significance | Effect Size | Level of Evidence |
|-------------------------------|-------------------|-----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|--------------------------------------------------------------------------------------------------------------------------------|-------------------------|-------------|-------------------|
| Lehtisalo et al21             | N=2816            | Healthy adults                    | Leisure time physical activity, housework or cleaning, and gardening as measured by an unvalidated self-reported questionnaire                                                                                                      | Descriptive statistics    | n=54 reported decrease (61.5%) n=12 reported no change (13.6%) n=22 reported increase (24.9%) n=91 reported decreased (34%) n=287 reported no change (50%) n=193 reported increased (16%) | NA                      |             | Very limited       |
| Lesser et al22                | N=1098            | Healthy adults                    | Walking/jogging/running/ biking/cycling/weight training/online video/classes/yoga/home workout/hiking/home/yard work/other as measured by the Behavioral Regulations in Exercise Questionnaire and Godin Leisure-Time Questionnaire | Descriptive statistics    | n=372 reported decrease (33.9%) n=334 reported no change (30.4%) n=392 reported increase (35.7%)                                                                                        | NA                      |             | Very limited       |
| Paltrinieri et al25           | N=2816            | Healthy adults                    | Not defined                                                                                                                                                                                                                                                                                    | Descriptive statistics    | n=641 reported decrease (35.1%) n=972 reported no change (51.2%) n=97 reported increase (5.3%) n=116 were missing data (6.4%) n=308 reported decrease (20.7%) n=454 reported no change (30.5%) n=729 reported increase (48.9%) | NA                      |             | Very limited       |
| Stanton et al22               | N=1491            | Healthy adults                    | PA as defined by Active Australian Survey                                                                                                                                                                                                                                                | Descriptive statistics    | Never carry out PA: increased from n=86 to n=113 (by 31%) Occasionally carry out PA: decreased from n=272 to n=213 (by 21.7%) Frequently carry out PA: increased from n=114 to n=146 (by 28.3%) | NA                      |             | Very limited       |
| Rodriguez-Nogueira et al33    | N=472             | Healthy adults                    | Aerobics, strengthening exercise, others, and no exercise, as well as the frequency of doing exercise as measured by an unvalidated self-developed questionnaire Occasionally carry out PA: some d/mo Frequently carry out PA: 7 d/wk as measured by IPAQ | Descriptive statistics    | Level of activity reported by participants                                                                                                                                                                                                 | NA                      |             | Very limited       |
| Ruiz-Roso et al30             | N=726             | Adolescents                       | Active: PA ≥300 min/wk as measured by IPAQ                                                                                                                                                                                                                                                   | Descriptive statistics    | Active population: decreased from n=206 to n=135 (by 34.5%) Inactive population: increased from n=86 to n=157 (by 82.5%)                                                                 | NA                      |             | Very limited       |
| Sonza et al31                 | N=3194            | Healthy adults                    | Aerobics, resistance, and strength exercise as measured by the Physical Exercise Level Before and During Social Isolation Questionnaire Level of activity reported by participants                                                                                                                                 | Descriptive statistics    | “A bit active” population: increased from n=866 to n=1086 (from 27.1% to 35%) Active population: decreased from n=1412 to n=1044 (from 44.2% to 32.7%) Very active population: decreased from n=527 to n=265 (from 16.5% to 8.3%) | NA                      |             | Very limited       |
| MET-min/wk (N=3)              |                   |                                  |                                                                                                                                                                                                                                                                                              | Student t test            | Decreased from 1826 MET-min/wk to 552 MET-min/wk (by 69.8%) Low PA: increased 18.2% in MET-min/wk Moderate PA: increased 10.1% in MET-min/wk                                                                                                                                 | P<.005                   | Small        | Very limited       |
| Arturo et al7                 | N=37              | Healthy adults                    | PA as defined by IPAQ*                                                                                                                                                                                                                                                                        | Paired t test             | Decreased from 2269.2 MET-min/wk to 1728 MET-min/wk (by 23.8%)                                                                                                                                                                               | P=.001                   |             | Very limited       |
| Orlandi et al24               | N=2218            | Healthy adults                    | PA as defined by IPAQ*                                                                                                                                                                                                                                                                        | Paired t test             | Decreased from 2205±3342.7 MET-min/wk to 1616±2176.6 MET-min/wk (by 26.7%)                                                                                                                                                                           | P<.001                   |             | Very limited       |
| Weaver et al36                | N=362             | Healthy adults                    | PA as defined by IPAQ*                                                                                                                                                                                                                                                                        | Paired t test             |                                                                                                                                                                                                                                                  |                         |             |                   |

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| Author          | Study Sample Size | Study Population                        | Definition of PA-Related Outcomes                                                                 | Statistical Test | Results                                                                 | Level of Significance | Effect Size | Level of Evidence |
|-----------------|-------------------|-----------------------------------------|----------------------------------------------------------------------------------------------------|-----------------|-------------------------------------------------------------------------|-----------------------|-------------|-------------------|
| Ammar et al6    | N=1047            | Healthy adults                          | IPAQ scores (N=1)                                                                                   | Paired t test   | Decreased from 5.04±2.51 to 3.83±2.84 (by 24%)                         | P<.001                | Very limited |                   |
| Deng et al11    | N=1607            | Healthy adults                          | Time spent on exercise during COVID-19 (including web-based physical education) as measured by an unvalidated self-developed questionnaire | Descriptive     | n=826 reported less time (51.4%)                                      | NA                    | Limited     |                   |
| Hu et al18      | N=1033            | Healthy adults                          | Exercise as defined by IPAQ (eg, dancing and running) at 4 mo before COVID-19 and 4 mo after COVID-19 as measured by an unvalidated self-developed questionnaire | Descriptive     | n=195 reported decrease (18.9%)                                      | NA                    | NA          |                   |
| Barrea et al17  | N=121             | Healthy adults                          | ≥30 min/d of aerobic exercise                                                                        | χ² test         | Decreased from n=62 (51.2%) to n=39 (32.2%)                             | P=.004                | Conflicting |                   |
| Di Renzo et al12| N=3533            | Healthy adults                          | ≥30 min/d of aerobic exercise At least once/wk of training (eg, walking/gym/run/swimming/soccer/volleyball/basketball/Cross Fit/dance/yoga/aerobic fitness/martial arts/tennis/aerial gymnastics) | Descriptive     | Reported training: increased from n=2173 to n=2198 (by 1.2%) reported no training: decreased from n=1360 to n=1335 (by 1.8%) | NA                    | NA          |                   |
| Jia et al19     | N=10,082          | High school, college, and graduate school students | Screen and sitting time as measured by IPAQ                                                      | Paired t test   | Increased from 4.9±1.9 h/d to 5.6±2.2 h/d (by 14.3%)                   | P<.001                | Small       | Very limited     |
| Weaver et al36  | N=362             | Healthy adults                          | Sitting time as measured by IPAQ-Short Form                                                        | Paired t test   | Increased from 460.9±281.6 min/d to 494.5±211.5 min/d (by 7.4%)        | P<.001                | NA          |                   |
| Zhu et al38     | N=889             | Healthy adults                          | Sedentary time as measured by an unvalidated self-developed questionnaire                          | Paired t test   | Increased from 5.3±2.7 h/d to 6.6±3.1 h/d (by 24.5%)                   | P<.001                | NA          |                   |
| Cooper et al10  | N=1,607           | Healthy adults                          | Screen and sitting time as measured by IPAQ-Short Form                                             | Descriptive     | Screen time: n=79 reported decrease (6.9%)                             | NA                    | Limited     |                   |
| Dunton et al16  | N=211             | Healthy children                        | Sitting time as measured by the Active Where questionnaire                                         | Descriptive     | n=662 reported no change (41.2%)                                      | NA                    | NA          |                   |
| Hu et al18      | N=1033            | Healthy adults                          | Screen time as measured by IPAQ                                                                      | Descriptive     | n=886 reported increase (53.9%)                                       | NA                    | NA          |                   |
| Sonza et al31   | N=3194            | Healthy adults                          | Sedentary behavior as measured by the Physical Exercise Level Before and During Social Isolation Questionnaire | Descriptive     | n=939 reported increase (58.5%)                                      | NA                    | NA          |                   |

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IPAQ scores
Very limited evidence from 1 study reported a 24.0% decrease in IPAQ scores, although it was described in MET-minutes.6

Sedentary time
Very limited evidence suggested approximately 7.4%-24.5% increases in sedentary time (defined by screen time, sitting, and sedentary activities) in the general public as measured by IPAQ19,36 or a self-developed questionnaire.38 Our meta-analysis showed a significant increase in sedentary time with a small effect size (pooled SMD=0.09, P=.04, I²=84%).19,36,38

Proportions of participants reported changes in sedentary time
There was limited evidence that a relatively larger proportion of participants reported increases in sedentary time in countries imposing lockdowns.10,16,18,31 Approximately 41.0%-68.3% of participants reported increases in their sedentary time.10,16,18 One study also found that the proportion of participants being classified as the “sedentary” category increased from 12.2% to 25.0%.31 All these studies adopted validated questionnaires to quantify sedentary time.10,16,18,31 Conversely, very limited evidence suggested that Swedish participants (without lockdown) were less likely to adopt a sedentary lifestyle.56 Only 26.0% of Swedish participants reported increased sitting time, while 66.0% reported no change.56

People with chronic diseases

Step counts (per d/wk)
Very limited evidence suggested significant decreases in step counts by 7.6% in patients with T2D.29 Similarly, there was very limited evidence that patients with cardiovascular diseases had approximately 16.4% reduction in step counts.34

Duration of MVPA
Very limited evidence supported no significant change in the duration of MVPA in patients with T2D as quantified by accelerometers.29 Conversely, very limited evidence substantiated 25.0% increases in MVPA among patients with cardiovascular diseases as measured by a validated questionnaire.33

Duration of PA
There was very limited evidence that patients with heart failure displayed an average of 0.8 hours reduction in daily duration of PA as measured by cardiac implantable electronic devices.5

Proportion of participants reported change in PA levels
Very limited evidence suggested significant decreases in PA levels among approximately 41% of patients with congestive heart failure 9 or adults with obesity.23

Changes in number of participants involving in different PA categories
Very limited evidence showed an increased number of participants classified as no activity in patients with musculoskeletal pain27 or low PA categories in children with chronic respiratory diseases.39 Specifically, 1 study showed a 82.5% increase in the number of participants being classified as “no PA,”27 while another study revealed a 237.5% increase in the number of participants being classified as having less than 1-2 hours of PA per day.39
Frequency of continuous PA
Very limited evidence supported an increase in the frequency of continuous PA in patients with T2D as recorded by an accelerometer.29 Rowlands et al revealed that the average frequency of 30- and 60-minute continuous PA in patients with T2D significantly increased from 0.65 d/wk to 1.0 d/wk and from 0.24 d/wk to 0.44 d/wk, respectively.29

Sedentary time
Very limited evidence supported a 3.0% increase in sedentary time in patients with T2D as measured by accelerometers29 and a 14.4% increase in patients with cardiovascular disease documented by a validated questionnaire.33

Proportion of participants reporting increases in sedentary time
Very limited evidence suggested that 46% of participants with congestive heart failure9 and 35% of participants with musculoskeletal pain27 reported increases in sedentary time.

Discussion
This systematic review and meta-analysis summarized evidence regarding changes in PA among people with and without chronic diseases during the COVID-19 pandemic. Twelve and 8 PA-related variables were used to evaluate changes in PA levels among people with and without chronic diseases, respectively. Moderate evidence from objective measurements (eg, accelerometers) substantiated decreases in step counts in people without chronic diseases during the pandemic. Very limited to limited evidence supported decreases in PA levels and exercise behaviors but increases in sedentary time in both groups, although 2 studies reported increases in continuous PA and MVPA among patients with T2D and cardiovascular diseases, respectively. People living in countries with lockdowns showed significant reductions in PA and increases in sedentary behaviors. The lockdown policy and closure of public facilities refrained people from performing PA.28 This is attested by the fact that most respondents in a country without lockdown reported no change in their PA and sedentary behaviors.36

Effects of physical inactivity on global health
It is well-known that physical inactivity adversely affect physical and mental health, as well as quality of life.57 Insufficient PA heightens the risk of developing noncommunicable diseases (eg, 24%, 16%, and 42% increase in the risk of having coronary heart disease, cardiovascular accident, and T2D, respectively).57 Because 23.3% and 27.5% of the global population had insufficient PA in 2010 and 2016, respectively,57 the WHO implemented an action plan between 2018 and 2030 to counteract physical inactivity58 and to reduce the global physical inactivity by 10% in 2025 and 15% in 2030.59 However, the COVID-19 pandemic could adversely affect the attainment of the original WHO 2025 global PA target.

Our meta-analysis and a prior systematic review45 highlight the negative effect of the COVID-19 pandemic on PA of people with and without chronic diseases globally. Home confinement policies and public facilities closure have heightened the prevalence of global physical inactivity. Lockdown-related physical inactivity may increase the incidence of noncommunicable diseases and...
related health care burdens. It is well known that regular MVPA boosts immunity against infectious diseases. An average energy expenditure of 500-1000 MET-minutes per week is associated with a lower risk of SARS-CoV-2 infection. PA can also improve an individual’s depression and mood by the augmented release of endorphins. Thereby, health authorities should implement new strategies to promote active lifestyle (especially MVPA) during and after lockdowns. Because some people may fear going out even after lockdowns are lifted, governments should run proper campaigns and/or use mobile applications to promote indoor PA and exercises among people who hesitate to exercise outdoor during or after lockdowns.

Effect of physical inactivity on people with chronic diseases

Most of the included studies reported decreases in PA among people with chronic diseases during the pandemic. Physical inactivity may have greater detrimental effects on people with chronic diseases. Increased physical inactivity in patients with chronic heart conditions could heighten their morbidity and mortality rates. A 30-minute reduction of daily PA in any given month during 4 years in patients after implanting cardioverter defibrillators was associated with 48% increased hazard for death compared with active patients in the same month. Similarly, physical inactivity and suspended face-to-face physiotherapy treatments during lockdowns led to increased symptoms in patients with musculoskeletal pain compared with the prepandemic period. Increased frequency and intensity of pain in patients with osteoarthritis or chronic low back pain in turn may result in the adoption of a sedentary lifestyle. If this vicious cycle persists, these patients may experience other pain-related comorbidities (eg, depression). Imperatively, decreased PA levels and the suspension of routine medical care in children with chronic respiratory diseases may lead to weight gain and mental health issues during the pandemic.

While reduced PA during the COVID-19 pandemic is prevalent, some people with chronic diseases reported increased PA during lockdowns. One included study reported no significant change in the duration of MVPA and even increases in the frequency of 30- and 60-minute exercise sessions among people with T2D. These findings might be attributed to the success of the British government in promoting exercise for health maintenance and permitting outdoor exercises during lockdowns. Similarly, increased population interest regarding medical care in children with chronic respiratory diseases may lead to weight gain and mental health issues during the pandemic.

Changes in exercise formats

During lockdowns, exercise formats have shifted from outdoors to indoors and from on-field team sports to home-based individual exercises (eg, yoga). Additionally, tele-exercise has gained popularity. Some governments produced online exercise videos by physiotherapists to promote home-based training to the general public. Similarly, nongovernment organizations (eg, National Centre of Health, Physical Activity, and Disability) launched different campaigns (eg, #MoveInMay, online toolkits, workout videos) via social media to engage and educate people to perform PA. While some private companies (eg, ParticipACTION) used websites and/or mobile applications to provide users with exercise demonstration videos and guidelines, interactive team challenges, and rewarding schemes to counteract the lockdown-related physical inactivity, other companies embedded a body positional tracking system in a mirror to provide individualized home exercise training. Although telehealth may facilitate home-based disease management, older people or underprivileged individuals may have difficulty in using telehealth.

Future studies should investigate the optimal strategies for delivering telerehabilitation/tele-exercise to older people or people in low-income countries.

Validity and reliability of outcome measures

Wearable devices (eg, smart watches) allow objective PA measurements. All included studies using wearable or implanted devices to quantify changes in PA-related variables following the pandemic are also important because they help reveal causation. However, self-reported PA levels may be subjected to recall bias. Therefore, PA levels estimated by online questionnaires might not be related to those measured by accelerometers. Further, while 30 included articles used different self-reported questionnaires to estimate PA, only 15 studies used self-reported PA questionnaires with reported reliability and validity. The estimated effects of the COVID-19 pandemic on PA might have been more accurate had validated questionnaires been used. Therefore, an international consortium should be formed to determine a core set of PA questionnaires (eg, global physical activity questionnaire) to allow comparisons of PA levels across studies in the future.

Study designs

Given the sudden onset of the pandemic, most of the included studies adopted a cross-sectional design. Twenty-three included studies evaluated the current PA levels. The remaining studies used questionnaires (n=7) or wearable or implanted devices to retrospectively evaluate the changes in PA levels before and after the outbreak. Cross-sectional studies are needed during a pandemic to cost-effectively garner relevant information from large samples to inform policy making and help plan further prospective studies. However, retrospective studies using wearable or implanted devices to quantify changes in PA-related variables following the pandemic are also important because they help reveal causation.
Study limitations

The current review had several limitations. First, the searched keywords might not be comprehensive enough to capture all relevant articles although most key articles have been included. Second, because diverse PA-related variables were used in the included studies, some variables were only used in 1 included study, which prevented the conduction of meta-analysis. Third, the included studies covered a range of chronic diseases, which prevented the conduction of meta-analysis of PA for each disease.

For limitations of the included studies, only 1 article reported PA-related variables in a country without lockdown, which limited its generalizability. Further, people’s PA levels may change over time. Their PA levels showed the greatest decline at the beginning of lockdowns, but PA levels increased toward the end of lockdowns.13, 26 Because some studies did not report the time of data collection, people’s PA levels at a given time point might not illustrate changes in PA levels throughout the pandemic. Moreover, many included studies recruited participants by convenience sampling or recruiting from a single center, which might affect the generalizability of results. Finally, although 3 PA-related variables were pooled for meta-analyses, they showed substantial heterogeneity ($I^2$>60%). The high heterogeneity might be attributed to differences in the sampling methods, delivery mode of questionnaires, durations spent on completing questionnaires, and socioeconomic status.

Conclusions

Moderate evidence from objective PA measurements demonstrated significant decreases in PA during the COVID-19 pandemic, while very limited to limited evidence from self-reported questionnaires revealed reduced PA and increased sedentary behaviors among people with and without chronic diseases during the COVID-19 pandemic globally. Tele-exercise may have the potential to help promote and/or maintain PA levels and exercise habits in people with and without chronic diseases. Future epidemiologic studies are warranted to determine the long-term effects of COVID-19 on the changes of PA and/or exercise habits and the associated health outcomes in people with and without chronic diseases worldwide. An international consortium should be established to determine the core set of PA measurements to allow comparisons of results across studies in the future. It would be prudent to include wearable devices or smartphones to reliably and objectively monitor PA. Collectively, the current review has laid the foundation for relevant stakeholders to develop and implement effective strategies to minimize the negative effects of similar outbreaks on PA and health of people with and without chronic diseases in the future.

Suppliers

a. EndNote X9; Clarivate.
b. Comprehensive Meta-analysis Version 3.3 software; Biostat.

Keywords

COVID-19; Exercise habit; Rehabilitation; SARS-CoV-2; Sedentary behavior

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Supplemental Digital Content 1. Search strategy

| Steps | Keywords |
|-------|----------|
| 1     | COVID* or Cov* or Corona* or Severe acute respiratory syndrome coronavirus 2 or SARS* |
| 2     | Physical activit* or activity level or Exercise habit* or Exercise routine* or lifestyle |
| 3     | 1 and 2 |

Supplemental Digital Content 2. Determination of overall risk of bias of the included studies and the level of evidence for a given outcome

| Risk of bias of a study | Description |
|-------------------------|-------------|
| High risk of bias       | For a study graded as high in at least two domains |
| Moderate risk of bias   | For a study graded as moderate in at least one domain, and rated as low in other domains |
| Low risk of bias        | For a study graded as low in all six domains |

| Level of evidence of PA-related outcome measures | Description |
|-------------------------------------------------|-------------|
| Strong evidence                                 | Pooled results from two or more studies, at least two of them have high quality; or consistent narrative findings in multiple studies with high-quality |
| Moderate evidence                               | Significant pooled results from multiple statistically heterogeneous studies, at least one of them has high quality; or consistent findings from multiple studies with at least one high quality study |
| Limited evidence                                | Findings from a high-quality study, or consistent findings from multiple moderate- or low-quality studies |
| Very limited evidence                           | Findings from one moderate- or low-quality study |
| Conflicting evidence                            | Inconsistent findings |
## Appendix 3. Risk of bias of the included cross-sectional studies

| Study | Objective & study design | Study participation | Handling of non-respondents | Outcome measures | Statistical analysis | Reporting | Overall risk |
|-------|--------------------------|---------------------|----------------------------|-----------------|---------------------|-----------|--------------|
|       | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13* | 14 | 15 | 16 | 17 | 18 | 19* | S |   |
| Ammar et al. (2021) | Y | Y | L | N | N | Y | Y | Y | M | N | N | N | H | Y | Y | L | Y | Y | L | Y | Y | Y | Y | N | M | Moderate |
| Arturo et al. (2020) | Y | Y | L | N | Y | N | N | Y | M | N | N | N | N | Y | H | Y | L | Y | L | Y | N | Y | Y | Y | ? | M | Moderate |
| Blom et al. (2021) | Y | Y | L | N | Y | N | Y | Y | M | N | Y | Y | M | Y | Y | L | Y | Y | L | Y | Y | Y | Y | Y | L | Moderate |
| Chague et al. (2020) | Y | Y | L | N | Y | Y | Y | Y | M | N | Y | M | Y | Y | M | L | Y | Y | L | Y | Y | Y | N | Y | M | Moderate |
| Cooper et al. (2021) | Y | Y | L | N | Y | N | Y | Y | M | Y | ? | Y | M | Y | Y | L | Y | Y | Y | L | Y | Y | Y | Y | N | M | Moderate |
| Deng et al. (2020) | Y | Y | L | N | Y | Y | Y | Y | M | Y | ? | Y | M | Y | Y | L | N | Y | N | Y | M | Y | L | Y | Y | Y | N | M | Moderate |
| Di Renzo et al. (2020) | Y | Y | L | N | Y | Y | Y | Y | M | N | ? | N | H | Y | Y | L | Y | Y | N | M | Y | Y | Y | Y | N | M | Moderate |
| Doğan et al. (2020) | Y | Y | L | N | Y | Y | Y | Y | M | N | ? | N | H | Y | Y | L | Y | Y | Y | N | M | Y | Y | Y | Y | N | M | Moderate |
| Duncan et al. (2020) | Y | Y | L | N | Y | Y | Y | Y | M | N | N | N | H | Y | N | M | N | N | Y | L | Y | Y | Y | N | M | Moderate |
| Galle et al. (2020) | Y | Y | L | Y | Y | Y | Y | L | N | Y | N | H | Y | Y | L | N | N | M | Y | Y | Y | Y | N | M | Moderate |
| Hu et al. (2020) | Y | Y | L | N | Y | Y | Y | Y | M | N | Y | Y | Y | Y | Y | L | L | Y | Y | Y | N | M | Moderate |
| Lehtisalo et al. (2021) | Y | Y | L | N | Y | Y | Y | Y | M | N | N | N | N | H | Y | L | Y | Y | Y | N | M | Moderate |
| Lesser et al. (2020) | Y | Y | L | N | Y | Y | Y | Y | M | N | ? | N | H | Y | Y | L | Y | Y | Y | N | M | Moderate |
| Minsky et al. (2021) | Y | Y | L | N | Y | Y | Y | Y | M | N | Y | N | H | Y | N | M | Y | Y | L | Y | Y | Y | Y | N | M | Moderate |
| Orlandi et al. (2021) | Y | Y | L | N | Y | Y | Y | Y | M | N | ? | N | H | Y | Y | L | Y | Y | Y | N | M | Moderate |
| Paltrinieri et al. (2021) | Y | Y | L | N | Y | Y | Y | Y | M | N | N | N | H | Y | N | N | N | N | L | Y | Y | Y | Y | N | M | Moderate |
| Persiani et al. (2021) | Y | Y | L | N | Y | Y | Y | Y | M | N | N | N | H | Y | Y | L | Y | Y | Y | N | M | Moderate |
| Rodríguez-Nogueira et al. (2021) | Y | Y | L | N | Y | Y | Y | Y | M | N | N | N | H | Y | N | M | Y | Y | L | Y | Y | Y | N | M | Moderate |
| Ruíz-Roso et al. (2020) | Y | Y | L | N | N | Y | Y | Y | M | N | N | N | N | H | Y | N | M | Y | Y | L | Y | Y | Y | Y | M | Moderate |
| Sonza et al. (2021) | Y | Y | L | N | Y | Y | Y | Y | M | N | N | N | H | Y | Y | L | Y | Y | Y | N | M | Moderate |
| Stanton et al. (2020) | Y | Y | L | N | Y | Y | Y | Y | M | N | N | N | H | Y | Y | L | Y | Y | Y | N | M | Moderate |
| Yamada et al. (2020) | Y | Y | L | N | Y | Y | Y | Y | M | N | N | N | H | Y | Y | L | Y | Y | Y | N | M | Moderate |
| Zhu et al. (2021) | Y | Y | L | N | Y | Y | Y | Y | M | N | N | N | H | Y | Y | L | Y | Y | Y | N | M | Moderate |

% of studies that reported “yes”/no bias

| % of studies that reported “yes”/no bias | 100 | 100 | 9 | 83 | 78 | 87 | 100 | 83 | 13 | 13 | 100 | 74 | 83 | 96 | 96 | 100 | 100 | 100 | 96 | 15 |

H = High; M = Moderate; L = Low; ? = Uncertain; N = No; Y = Yes; S = Subscore

* For item number 13 and 19 in the AXIS, a point is rewarded when the content is “N.”
### Appendix 4. Risk of bias of the included retrospective studies

| Study                              | Subject participation | Study attrition | Prognostic factor measurement | Outcome measurement | Study confounding | Statistical analysis and reporting | Overall risk |
|------------------------------------|-----------------------|-----------------|-------------------------------|---------------------|-------------------|-----------------------------------|--------------|
| Original item number               | 1 2 3 4 5 6 7 S       | 1 2 3 4 5 S     | 1 2 3 4 5 S                   | 1 2 3 4 5 S         | 1 2 3 4 5 S       | 1 2 3 4 5 S                       |              |
| Al Fagih et al. (2020)5            | P N Y Y P U Y H N N/A N/A N/A N/A H P P Y N N/A H P Y Y H N N N/A N/A N/A N/A H Y Y Y U M |                |                               |                     |                   |                                   | High         |
| Barrea et al. (2020)6              | P N N Y P Y Y M N N/A N/A N/A N/A H P N Y Y N/A M Y N M N N N/A N/A N/A N/A N/A H Y Y Y Y L |                |                               |                     |                   |                                   | Moderate     |
| Di Sebastiani et al. (2020)7       | Y N Y Y P Y Y M Y N N/A N/A N/A N/A M Y Y Y Y N/A L P P P M N N N/A N/A N/A N/A N/A H Y Y Y Y L |                |                               |                     |                   |                                   | Moderate     |
| Dunton et al. (2020)8              | Y P Y P U Y M Y P Y N N/A M P N Y N/A H Y N Y M Y N N/A N/A N/A N/A H Y Y Y Y L |                |                               |                     |                   |                                   | Moderate     |
| Jia et al. (2020)9                 | Y Y Y Y P Y Y L N/A N/A N/A N/A H P Y Y Y N/A M Y Y L Y Y Y Y N/A Y Y M Y Y Y L |                |                               |                     |                   |                                   | Moderate     |
| Keel et al. (2020)10               | Y P P N U Y M N/A N/A N/A N/A H Y Y U N/A M Y N Y M P N Y N/A P N H Y Y Y U L |                |                               |                     |                   |                                   | Moderate     |
| Pepin et al. (2020)26              | Y N Y P N U Y M N/A N/A N/A N/A H Y Y U N/A M Y Y L P N P U N/A P N H P Y U M |                |                               |                     |                   |                                   | Moderate     |
| Rowlands et al. (2021)28           | Y Y Y Y Y Y L Y N/A N/A N/A N/A H Y Y Y N/A L Y Y L Y Y Y N/A Y N M Y Y U L |                |                               |                     |                   |                                   | Low          |
| Van Bakel et al. (2021)30          | Y P Y P Y Y M P N/A N/A N/A N/A H Y Y Y N/A L Y Y M Y N P N A Y N M Y Y Y U L |                |                               |                     |                   |                                   | Moderate     |
| Vetrovsky et al. (2020)31          | Y P Y N U Y M N/A N/A N/A N/A H Y Y Y N/A M Y Y L P Y P Y N/A P N M Y Y Y L |                |                               |                     |                   |                                   | Moderate     |
| Wang et al. (2020)32               | Y Y Y Y P U Y M N N/A N/A N/A N/A H Y Y U N/A M Y Y L Y Y Y N/A Y N M Y Y Y L |                |                               |                     |                   |                                   | Moderate     |
| Weaver et al. (2021)33             | Y N Y Y P Y Y M N N/A N/A N/A N/A H Y Y Y N/A L Y Y L P P Y N/A P N M Y Y Y L |                |                               |                     |                   |                                   | Moderate     |
| Zorcec et al. (2020)34             | Y N Y P N U Y M N N/A N/A N/A N/A H Y Y Y N/A L Y N Y M Y N Y N/A Y N M Y Y Y U L |                |                               |                     |                   |                                   | Moderate     |

Y = Yes; N = No; P = Partial; U = Unclear; N/A = Not Applicable; S = Subscore
Appendix 5. Definitions of physical activity according to International Physical Activity Questionnaire (IPAQ) questionnaires

| Definition of PA according to IPAQ |
|-----------------------------------|
| **Category 1 Low intensity**       |
| This is the lowest level of physical activity. Individuals who do not meet the criteria for the categories 2 or 3 are considered low intensity/inactive. |
| **Category 2 Moderate intensity**  |
| Any one of the following 3 criteria: |
| - 3 or more days of vigorous activity for at least 20 minutes per day OR |
| - 5 or more days of moderate-intensity activity or walking for at least 30 minutes per day; OR |
| - 5 or more days of any combination of walking, moderate-intensity or vigorous intensity activities achieving a minimum of at least 600 MET-min/week. |
| **Category 3 High intensity**      |
| Any one of the following 2 criteria: |
| - Vigorous-intensity activity on at least 3 days and accumulating at least 1,500 MET-min/week OR |
| - 7 or more days of any combination of walking, moderate-intensity or vigorous intensity activities achieving a minimum of at least 3,000 MET-min/week. |

**MET-min** = Metabolic equivalent of task-minutes

Appendix 6. Definitions of physical activity according to the Active Australian Survey

| Physical activity          | Definition                                                                 |
|----------------------------|----------------------------------------------------------------------------|
| Walking                   | Continuous in 10-minute intervals of walking                               |
| Gardening/yardwork        | No description available                                                  |
| Other moderate activities | Activities that make you “breathe somewhat harder than normal and slightly increase heart rate” |
| Other vigorous activities | Activities that make you “breathe much harder than normal and have a greater effect on heart rate” |

Duration of total activity time = time spent on walking + time spent on moderate activities + (2 x time spent of vigorous activities)

Appendix 7. Interpretation of acceleration in milli-gravitation units

| Interpretation of acceleration in milli-gravitation units (mg) |
|---------------------------------------------------------------|
| Time spent:                                                  |
| 100-200 mg                                                   | Slow walking |
| 200-350 mg                                                   | Brisk walking |
| 350-500 mg                                                   | Fast walk / jog |
| 500-1000mg                                                   | Slow run |
| 1000-1500mg                                                  | Medium run |
| 1500-2000mg                                                  | Fast run |
| >2000mg                                                      | Sprint |

Conversion from milli-gravitation unit to number of steps based on suggestion of 1.7 mg being equivalent to ~800 steps/day as suggested by Rowlands et al.29
### Appendix 8. Quality of evidence of PA-related outcome variables in people without chronic diseases

| Potential outcomes identified | Number of participants | Number of studies | Number of cohorts | Univariate Phase | Study limitations | Inconsistency | Indirectness | Imprecision | Publication bias | Moderate/large effect size | Dose effect | Overall quality |
|------------------------------|------------------------|-------------------|-------------------|------------------|------------------|--------------|--------------|-------------|----------------|-----------------------|-------------|-----------------|
| **Lockdown**                |                        |                   |                   |                  |                  |              |              |             |                |                      |             |                 |
| MET-minute per week          | 2,617                  | 3                 | 3                 | 3                | 1                | X            | ✓            | ✓           | ✓              | X                     | X           | X               |
| Duration of PA              | 6,118                  | 3                 | 3                 | 3                | 1                | X            | ✓            | ✓           | ✓              | X                     | X           | X               |
| Duration of light PA         | 2,338                  | 1                 | 1                 | 1                | 1                | X            | ✓            | ✓           | ✓              | X                     | X           | ✓               |
| Duration of MVPA            | 12,420                 | 2                 | 2                 | 1                | 1                | X            | X            | X           | X              | ✓                     | X           | X               |
| Proportion of participants reported changes in PA levels | 16,014                 | 8                 | 8                 | N/A             | 1                | X            | X            | X           | X              | ✓                     | N/A         | N/A             |
| Changes in number of participants involving in different PA categories | 4,392                  | 3                 | 3                 | N/A             | 1                | X            | X            | X           | X              | ✓                     | N/A         | N/A             |
| IPAQ scores                 | 1,047                  | 1                 | 1                 | 1                | 1                | X            | ✓            | ✓           | ✓              | X                     | X           | X               |
| Step counts (per day or per week) | 748,971               | 4                 | 4                 | 4                | 1                | X            | ✓            | ✓           | ✓              | ✓                     | ✓           | ✓               |
| Proportion of participants reported changes in exercise duration | 2,640                  | 2                 | 2                 | N/A             | 1                | ✓            | ✓            | ✓           | ✓              | N/A                   | N/A         | ++              |
| Proportion of participants reported doing regular exercise | 3,654                  | 2                 | 2                 | 1                | 1                | X            | X            | X           | X              | ✓                     | N/A         | N/A             |
| Duration of sedentary time  | 11,333                 | 3                 | 3                 | 3                | 1                | X            | ✓            | ✓           | ✓              | ✓                     | ✓           | ++              |
| Proportion of participants reported changes in sedentary time | 6,045                  | 4                 | 4                 | N/A             | 1                | ✓            | ✓            | ✓           | ✓              | X                     | X           | X               |
| **No lockdown**             |                        |                   |                   |                  |                  |              |              |             |                |                      |             |                 |
| Proportion of participants reported changes in PA | 5,599                  | 1                 | 1                 | N/A             | 1                | ✓            | N/A          | ✓           | X              | X                     | X           | X               |
| Proportion of participants reported changes in exercise duration | 5,599                  | 1                 | 1                 | N/A             | 1                | ✓            | N/A          | ✓           | X              | X                     | X           | X               |
| Proportion of participants reported changes in sedentary time | 5,599                  | 1                 | 1                 | N/A             | 1                | ✓            | N/A          | ✓           | X              | X                     | X           | X               |

IPAQ = International Physical Activity Questionnaire; MET-min = metabolic equivalent-minute; MVPA = moderate-to-vigorous physical activity; PA = physical activities

Phase, phase of investigation. For univariate analysis: +, number of significant effects with a positive value; 0, number of non-significant effects; -, number of significant effects with a negative value. For GRADE factors: ✓, no serious limitations; X, serious limitations (or not present for moderate/large effect size, dose effect); ?, unable to rate item based on available information; N/A, not applicable. For overall quality of evidence: -., inconsistent; +, very low; ++, low; ++++, moderate; ++++, high

PA = physical activities; MVPA = moderate-to-vigorous physical activity

Phase, phase of investigation. For univariate analysis: +, number of significant effects with a positive value; 0, number of non-significant effects; -, number of significant effects with a negative value. For GRADE factors: ✓, no serious limitations; X, serious limitations (or not present for moderate/large effect size, dose effect); ?, unable to rate item based on available information; N/A, not applicable. For overall quality of evidence: +, very low; ++, low; ++++, moderate; ++++, high
## Appendix 9. Quality of evidence of PA-related outcome variables for people with chronic diseases

| Potential outcomes identified | Number of participants | Number of studies | Number of cohorts | Univariate (+) Phase | Study limitations | Inconsistency | Indirectness | Imprecision | Publication bias | Moderate/large effect size | Dose effect | Overall quality |
|------------------------------|------------------------|-------------------|------------------|---------------------|------------------|--------------|-------------|-------------|----------------|---------------------------|--------------|-----------------|
| Duration of PA               |                        |                   |                  |                     |                  |              |             |             |                |                           |              |                 |
| Patients with heart failure  | 82                     | 1                 | 1                | X                   | N/A              | ✓            | X           | ✓           | ✓              | ✓                        | ✓            | N/A +           |
| Duration of MVPA             |                        |                   |                  |                     |                  |              |             |             |                |                           |              |                 |
| Patients with type 2 diabetes mellitus | 165                 | 1                 | 1                | ✓                   | N/A              | ✓            | X           | ✓           | ✓              | ✓                        | ✓            | N/A +           |
| Patients with cardiovascular disease | 1,565            | 1                 | 1                | ✓                   | N/A              | ✓            | X           | ✓           | ✓              | ✓                        | ✓            | N/A +           |
| Proportion of participants reported changes in PA levels |                        |                   |                  |                     |                  |              |             |             |                |                           |              |                 |
| Patients with congestive heart failure | 124                 | 1                 | 1                | N/A                 | X                | N/A          | ✓           | X           | X              | N/A                      | N/A          | N/A +           |
| Adults with obesity          | 279                    | 1                 | 1                | N/A                 | X                | N/A          | ✓           | X           | X              | N/A                      | N/A          | N/A +           |
| Changes in number of participants involving in different PA categories |                        |                   |                  |                     |                  |              |             |             |                |                           |              |                 |
| Patients with musculoskeletal pain | 292                 | 1                 | 1                | N/A                 | 1                | X           | N/A          | X           | X              | ✓                        | N/A          | N/A +           |
| Children with chronic respiratory diseases | 72                   | 1                 | 1                | N/A                 | 1                | ✓            | N/A          | X           | X              | ✓                        | N/A          | N/A +           |
| Step counts (per day or per week) |                        |                   |                  |                     |                  |              |             |             |                |                           |              |                 |
| Patients with type 2 diabetes mellitus | 165                 | 1                 | 1                | ✓                   | N/A              | ✓            | X           | ✓           | ✓              | ✓                        | ✓            | N/A +           |
| Patients with heart failure  | 26                     | 1                 | 1                | X                   | N/A              | ✓            | X           | ✓           | ✓              | ✓                        | ✓            | N/A +           |
| Frequency of continuous PA   |                        |                   |                  |                     |                  |              |             |             |                |                           |              |                 |
| Patients with type 2 diabetes mellitus | 165                 | 1                 | 1                | ✓                   | N/A              | ✓            | X           | ✓           | ✓              | ✓                        | ✓            | N/A +           |
| Duration of sedentary time   |                        |                   |                  |                     |                  |              |             |             |                |                           |              |                 |
| Patients with type 2 diabetes mellitus | 165                 | 1                 | 1                | ✓                   | N/A              | ✓            | X           | ✓           | ✓              | ✓                        | ✓            | N/A +           |
| Patients with cardiovascular disease | 1,565              | 1                 | 1                | ✓                   | N/A              | ✓            | X           | ✓           | ✓              | ✓                        | ✓            | N/A +           |
| Proportion of participants reported changes in sedentary time |                        |                   |                  |                     |                  |              |             |             |                |                           |              |                 |
| Patients with congestive heart failure | 124                 | 1                 | 1                | ✓                   | N/A              | ✓            | X           | X           | X              | N/A                      | N/A          | N/A +           |
| Patients with musculoskeletal pain | 292                 | 1                 | 1                | N/A                 | X                | N/A          | X           | X           | ✓              | N/A                      | N/A          | N/A +           |

Note: GRADE factors: + indicates high quality, X indicates low quality.