Changes in health promoting behavior during COVID-19 physical distancing: Utilizing
WHOOP data to Examine Trends in Sleep, Activity, and Cardiovascular Health.

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NOTE: This preprint reports new research that has not been certified by peer review and should not be used to guide clinical practice.
Abstract

The COVID-19 pandemic incited global and unprecedented restrictions on the behavior of society. The aims of this study were to quantify changes to sleep/wake behavior and exercise patterns (e.g., exercise frequency, modality, and intensity), and the subsequent impact on physiological markers of health (e.g., total sleep duration, social jet lag, resting heart rate, and heart rate variability) with the introduction of physical distancing mandates and recommendations. A retrospective analysis of 50,000 subscribers to the WHOOP platform (mean age = 36.6 ± 10.5; 11,956 females, 38,044 males) was conducted covering the period from January 1st, 2020 through May 15th, 2020. In order to make robust comparisons, this time period was separated into a 68 day baseline period and a 67 day physical distancing period – with a total of 6.3 million sleeps and 4.9 million exercise sessions analyzed. As compared to baseline, during physical distancing, all subjects analyzed in this study dedicated more time to sleep (+0.21 hours), fell asleep earlier (-0.43 hours), woke up earlier (-0.29 hours), obtained more sleep (+0.19 hours) and reduced social jet lag (-0.23 hours). Subjects also increased exercise frequency by an average of 1.1% and increased exercise intensity by spending an average of 1.8% more time in the three highest heart rate zones. These changes to sleep and exercise behavior may have contributed to the observed lowered resting heart rate (-0.9 beats per minute) and increased heart rate variability (+1.3 milliseconds) during physical distancing. A potential explanation for these results is that decreases in business hours-based commitments during physical distancing may have resulted in increased opportunity to engage in exercise and prioritize sleep. Therefore, as the COVID-19 pandemic eases, maintenance of certain aspects of physical distancing (e.g., flexibility to work from home) may result in a healthier population.
Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the virus responsible for the COVID-19 pandemic [1], has caused significant social and economic disruptions and has altered the behavior of society. Millions of employees and business owners have stopped working or shifted to working from home rather than commuting into offices. Physical distancing protocols put in place to reduce disease transmission have also precluded previously common forms of group leisure and athletic activities. Exercise and sleep are two primary behaviors that may have been impacted by COVID-19 restrictions - with individuals confined to their homes and likely having increased opportunity to perform daily exercise and acquire more sleep.

Changes in sleep/wake behavior can have meaningful implications on health. Insufficient sleep duration has been shown to correlate with impairments to cognitive performance [2], insulin sensitivity [3] and diabetes [4], cardiovascular disease [5], impairments to mental health [6], and reduced physical performance [7]. Increasing sleep quantity has been shown to reverse many of these effects; for example, increases in sleep quantity have been shown to drive changes in attention [8] and stress hormone expression [9] even within already healthy populations. Changes in sleep timing and the consistency of bedtimes and wake times also have profound effects on wellbeing, with benefits seen when a consistent sleep schedule is maintained [10]. These benefits are understood to be related to the circadian rhythm; shifting sleep timing decouples the circadian rhythm from the sleep/wake rhythm [11, 12], causing adverse health outcomes such as higher rates of cardiovascular disease [13] and breast cancer [14].

Physical distancing mandates brought with them temporary closure of gyms, banning of team sports, and cancelations of competitive seasons, which in turn forced a shift in the way we exercise and the types of exercise we have access to. These sudden changes have a variety of
potential effects on fitness. For example, one study showed that women who participated in multiple exercise modalities had higher muscular endurance than women who participated in only one athletic activity [15]. Other studies suggest that rapid introduction of new exercise modalities, such as running, could lead to an increase in athletic injuries [16]. Sudden changes in the exercise modalities performed by individuals may also result in changes to exercise intensity (e.g., transitioning from weight training to running). Therefore, if COVID-19 restrictions do provide more opportunity for exercise, increases in exercise frequency and intensity may result in beneficial cardiovascular adaptations [17]. Understanding how the distribution of time spent in each heart rate zone is perhaps as important as understanding how total exercise and exercise modality changed as a result of the COVID-19 pandemic. In this context, wearable technology can be leveraged to provide a unique insight into health related behavior and subsequent health outcomes in large population cohorts.

The WHOOP strap (Whoop, Inc., Boston, MA, USA) is a commercially available wearable device that has been third-party validated to measure sleep, resting heart rate (RHR), heart rate variability (HRV), and respiratory rate [18]. Previous research has shown that metrics such as RHR [19] and HRV [20] are powerful indicators of physical health. Conditions brought forth by the pandemic create a natural testing ground in which to examine whether changes in cardiovascular health, as measured by decreases in RHR and increases in HRV, can occur due to changes in sleep and exercise behavior.

This study is the first to quantify the impact on health related behaviors – specifically sleep timing and duration and exercise frequency, intensity, and modality – of the COVID-19 pandemic and its associated physical distancing mandates. This study also explores the physical outcomes of
these changes in behavior by examining markers of physical health, including sleep duration, RHR, and HRV.

Materials and Methods

This study conducted a retrospective analysis of health-related behavior before and during COVID-19 physical distancing restrictions. 50,000 WHOOP members (mean age = 36.6 ± 10.5; 11,956 females, 38,044 males) meeting the study’s inclusion criteria were randomly selected from the WHOOP subscriber-base. Inclusion criteria were (1) having recorded sleeps for at least 120 of the 135 (89%) days and (2) be between the ages of 18 and 80 on May 15th, 2020, when data was extracted for analysis. The study was approved by the Central Queensland University Human Research Ethics Committee.

The period between January 1, 2020 and March 9th, 2020 was classified as a baseline period, while the period from March 10th, 2020 through May 15th, 2020 was classified as the physical distancing period. While no single date globally separates pre- and post-physical distancing, delineation of the data on March 9th is based on the rough timeline along which most users would have been subject to some level of physical distancing mandate or recommendation. During the week of March 9th, the World Health Organization officially classified COVID-19 as a pandemic [21] and US President, Donald Trump, declared a National State of Emergency [22]. The May 15th physical distancing end date was chosen such that the physical distancing period analyzed would end before gradual easing physical distancing begins. Additionally, utilizing the chosen dates to represent physical distancing resulted in similar durations of baseline and physical distancing (68 and 67 days, respectively).
WHOOP

The WHOOP strap (CB Rank, Greater Boston, New England) is a wearable device that collects continuous heart rate, 3-axis accelerometer, temperature, and 3-axis gyroscope data. In combination with the WHOOP mobile device app and cloud-analysis platform, a series of algorithms developed by WHOOP are collectively able to evaluate duration and phases of sleep, RHR and HRV. Validation of sleep and cardiovascular measures gleaned from WHOOP against gold standard polysomnography support a low degree of bias and low precision errors [18].

The WHOOP strap is capable of automatically detecting exercise and can automatically identify and classify 54 different modalities. Additionally, users of the WHOOP platform have the ability to manually log exercise that don’t meet the algorithm’s criteria for automatic detection.

The following variables were obtained from the WHOOP platform:

- **Sleep opportunity duration**: total time dedicated to sleep each night. Measured primarily through automatic detection in the WHOOP app. Users are alerted each morning when their automatically detected sleep is ready for review and have the ability to edit the start and stop times should any errors occur.

- **Social jet lag**: the difference between sleep opportunity onset on weekends (Saturday and Sunday) and weekdays (Monday through Friday) resulting from misalignment between social and internal clocks [23].

- **Sleep opportunity onset**: the time that each sleep opportunity was initiated relative to local time zone.

- **Sleep opportunity offset**: the time that each sleep opportunity ended relative to local time zone.
• Sleep duration (hours): total amount of time spent asleep each night. Measured through automatic detection.

• Exercise frequency: daily proportion of active WHOOP-users recording an exercise session.

• Exercise type - the sport or exercise type chosen for each exercise session. Labeled automatically by the app via a machine learning algorithm or manually by the WHOOP-user.

• Exercise intensity: duration of each of six heart rate zones - Zone 1 = 0-50% heart rate reserve (HRR); zone 2 = 50-60% HRR, zone 3 = 60-70% HRR, zone 4 = 70-80% HRR, zone 5 = 80-90% HRR, zone 6 = 90-100% HRR. Measured automatically during the exercise session.

• Resting heart rate (beats per minute; bpm) - the mean value of heart beats per minute sampled during slow wave sleep. Automatically measured during slow wave sleep each night.

• Heart rate variability (milliseconds; ms) - the root-mean-square difference of successive heartbeat intervals sampled during slow wave sleep. Automatically measured during slow wave sleep each night.

Throughout, dates are assigned to sleeps and exercise based on the local time zone’s date in which they end, for example, a sleep beginning in the final hours of January 1st and ending on the morning of January 2nd.

Data Analysis

All analyses were conducted at the cohort-level with data grouped by age (i.e., 18-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79 years old) and sex (i.e., male and female). Independent non-
parametric significance tests (Mann-Whitney U tests) were performed to examine differences in sleep and exercise variables between the baseline period and the physical distancing period. To assess the magnitude of the differences between these periods, effect sizes and 95% confidence limits were also calculated. Effect sizes were interpreted as: <0.20 (trivial), 0.2 to 0.59 (small), 0.60 to 1.19 (moderate), 1.20 to 1.99 (large), and >2.0 (very large) [24]. All analyses were conducted using Python Language Software (version 3.6.2).

**Results**

**Sleep**

A summary of sleep/wake behavior for age and gender cohorts are presented in Table 1. For all subjects, average sleep opportunity duration was significantly longer during physical distancing when compared to baseline ($P<10^{-8}$, Cohen’s $d = 1.27$, large). When analyzed by cohort, average sleep opportunity duration was significantly longer during physical distancing when compared to baseline for 18-19 year-olds ($P<10^{-16}$, Cohen’s $d = 1.94$, large), 20-29 year-olds ($P<10^{-14}$, Cohen’s $d = 1.92$, large), 30-39 year-olds ($P<10^{-7}$, Cohen’s $d = 1.27$, large), 40-49 year-olds ($P<10^{-5}$, Cohen’s $d = 0.95$, moderate), 50-59 year-olds ($P<10^{-5}$, Cohen’s $d = 0.87$, moderate), 60-69 year-olds ($P=0.0001$, Cohen’s $d = 0.53$, small), 70-79 year-olds ($P=0.16$, Cohen’s $d = 0.32$, small), females ($P<10^{-9}$, Cohen’s $d = 1.44$, large), and males ($P<10^{-7}$, Cohen’s $d = 1.21$, large) (Table 1).

For all subjects, average sleep opportunity onset was significantly earlier during physical distancing when compared to baseline ($P<10^{-21}$, Cohen’s $d = -2.61$, very large). When analyzed by cohort, average sleep opportunity onset was significantly earlier during physical distancing when compared to baseline for 18-19 year-olds ($P<10^{-8}$, Cohen’s $d = -1.11$, moderate), 20-29
year-olds ($P<10^{-15}$, Cohen’s $d = -1.91$, large), 30-39 year-olds ($P<10^{-21}$, Cohen’s $d = -2.55$, very large), 40-49 year-olds ($P<10^{-21}$, Cohen’s $d = -3.22$, very large), 50-59 year-olds ($P<10^{-21}$, Cohen’s $d = -3.83$, very large), 60-69 year-olds ($P<10^{-21}$, Cohen’s $d = -5.27$, very large), 70-79 year-olds ($P<10^{-22}$, Cohen’s $d = -6.07$, very large), females ($P<10^{-21}$, Cohen’s $d = -2.68$, very large), and males ($P<10^{-21}$, Cohen’s $d = -2.61$, very large) (Table 1).

For all subjects, average sleep opportunity offset was significantly earlier during physical distancing when compared to baseline ($P<10^{-9}$, Cohen’s $d = -1.10$, moderate). When analyzed by cohort, average sleep opportunity offset was similar for 18-19 year-olds during baseline and physical distancing ($P=0.016$, Cohen’s $d = 0.00$, trivial), and significantly earlier in physical distancing than in baseline for 20-29 year-olds ($P<10^{-8}$, Cohen’s $d = -0.80$, moderate), 30-39 year-olds ($P<10^{-9}$, Cohen’s $d = -1.14$, moderate), 40-49 year-olds ($P<10^{-9}$, Cohen’s $d = -1.25$, large), 50-59 year-olds ($P<10^{-10}$, Cohen’s $d = -1.54$, large), 60-69 year-olds ($P<10^{-19}$, Cohen’s $d = -2.36$, very large), 70-79 year-olds ($P<10^{-20}$, Cohen’s $d = -3.33$, very large), females ($P<10^{-8}$, Cohen’s $d = -0.95$, moderate), and males ($P<10^{-9}$, Cohen’s $d = -1.14$, moderate) (Table 1).
Table 1. Sleep/wake behaviour for age and gender cohorts as a function of time period.

| Variable                      | Time period                  | Outcomes                              |
|-------------------------------|------------------------------|---------------------------------------|
|                               | Baseline (M±SD)              | Physical distancing (M±SD)             | Difference (PD-BL) | Effect size (95% confidence limits) |
| Sleep opportunity duration (h)|                              |                                       |                    |                                  |
| All subjects                  | 7.64 ± 0.17                  | 7.85 ± 0.16                           | 0.21**             | 1.27 (0.209, 0.211)              |
| 18-19 year-olds              | 7.88 ± 0.16                  | 8.2 ± 0.17                            | 0.32**             | 1.94 (0.301, 0.339)              |
| 20-29 year-olds              | 7.71 ± 0.13                  | 7.99 ± 0.16                           | 0.28**             | 1.92 (0.277, 0.283)              |
| 30-39 year-olds              | 7.61 ± 0.17                  | 7.82 ± 0.16                           | 0.21**             | 1.27 (0.207, 0.213)              |
| 40-49 year-olds              | 7.56 ± 0.22                  | 7.75 ± 0.18                           | 0.19**             | 0.95 (0.185, 0.195)              |
| 50-59 year-olds              | 7.62 ± 0.21                  | 7.79 ± 0.18                           | 0.17**             | 0.87 (0.162, 0.178)              |
| 60-69 year-olds              | 7.8 ± 0.17                   | 7.89 ± 0.17                           | 0.09**             | 0.53 (0.076, 0.104)              |
| 70-79 year-olds              | 7.82 ± 0.17                  | 7.88 ± 0.17                           | 0.06**             | 0.32 (0.022, 0.098)              |
| Females                      | 7.79 ± 0.19                  | 8.05 ± 0.17                           | 0.26**             | 1.44 (0.255, 0.265)              |
| Males                        | 7.59 ± 0.17                  | 7.79 ± 0.16                           | 0.20**             | 1.21 (0.198, 0.202)              |
| Sleep opportunity onset time |                              |                                       |                    |                                  |
| All subjects                  | 23:07 ± 0:20                 | 22:24 ± 0:12                          | -0.43**            | -2.61 (-0.719, -0.714)           |
| 18-19 year-olds              | 23:42 ± 0:22                 | 23:22 ± 0:13                          | -0.20**            | -1.11 (-0.369, -0.298)           |
| 20-29 year-olds              | 23:27 ± 0:25                 | 22:47 ± 0:16                          | -0.40**            | -1.91 (-0.675, -0.658)           |
| 30-39 year-olds              | 23:06 ± 0:20                 | 22:23 ± 0:13                          | -0.43**            | -2.55 (-0.722, -0.711)           |
| 40-49 year-olds              | 22:54 ± 0:16                 | 22:11 ± 0:10                          | -0.43**            | -3.22 (-0.723, -0.711)           |
| 50-59 year-olds              | 22:45 ± 0:15                 | 21:59 ± 0:08                          | -0.46**            | -3.83 (-0.775, -0.758)           |
| 60-69 year-olds              | 22:31 ± 0:12                 | 21:41 ± 0:06                          | -0.50**            | -5.27 (-0.846, -0.820)           |
| 70-79 year-olds              | 22:41 ± 0:10                 | 21:53 ± 0:05                          | -0.48**            | -6.07 (-0.827, -0.773)           |
| Females                      | 22:52 ± 0:18                 | 22:12 ± 0:11                          | -0.40**            | -2.68 (-0.673, -0.660)           |
| Males                        | 23:12 ± 0:20                 | 22:28 ± 0:13                          | -0.44**            | -2.61 (-0.737, -0.729)           |
| Sleep opportunity offset time|                              |                                       |                    |                                  |
| All subjects                  | 6:48 ± 0:30                  | 6:19 ± 0:22                           | -0.29*             | -1.10 (-0.292, -0.288)           |
| 18-19 year-olds              | 7:37 ± 0:30                  | 7:37 ± 0:21                           | 0.00               | 0.00 (0.031, -0.031)             |
| 20-29 year-olds              | 7:13 ± 0:33                  | 6:50 ± 0:24                           | -0.23**            | -0.80 (-0.237, -0.223)           |
| 30-39 year-olds              | 6:46 ± 0:30                  | 6:16 ± 0:22                           | -0.30**            | -1.14 (-0.305, -0.295)           |
| 40-49 year-olds              | 6:30 ± 0:28                  | 5:59 ± 0:21                           | -0.31**            | -1.25 (-0.317, -0.303)           |
| 50-59 year-olds              | 6:25 ± 0:26                  | 5:50 ± 0:19                           | -0.35**            | -1.54 (-0.360, -0.340)           |
| 60-69 year-olds              | 6:21 ± 0:21                  | 5:38 ± 0:15                           | -0.43**            | -2.36 (-0.445, -0.415)           |
| 70-79 year-olds              | 6:35 ± 0:14                  | 5:50 ± 0:13                           | -0.45**            | -3.33 (-0.478, -0.422)           |
| Females                      | 6:42 ± 0:29                  | 6:18 ± 0:21                           | -0.24**            | -0.95 (-0.246, -0.234)           |
| Males                        | 6:50 ± 0:30                  | 6:20 ± 0:22                           | -0.30**            | -1.14 (-0.304, -0.296)           |

Notes: BL = baseline; PD = physical distancing; * = p-value <0.05; ** = p-value <0.001.
Fig 1. Daily average sleep opportunity onset time and sleep opportunity offset time by age cohort. Each cohort is plotted in a different color, indicted in the legend. Filled circles indicate Sundays; a gray vertical line separates baseline and physical distancing.

For all subjects, average sleep duration was significantly longer during physical distancing when compared to baseline ($P<10^{-8}$, Cohen’s $d = 1.31$, moderate). When analyzed by cohort, average sleep duration was longer during physical distancing when compared to baseline for 18-19 year-olds ($P<10^{-16}$, Cohen’s $d = 2.00$, very large), 20-29 year-olds ($P<10^{-15}$, Cohen’s $d = 1.99$, large), 30-39 year-olds ($P<10^{-8}$, Cohen’s $d = 1.24$, large), 40-49 year-olds ($P<10^{-5}$, Cohen’s $d = 0.97$, moderate), 50-59 year-olds ($P<10^{-5}$, Cohen’s $d = 0.82$, moderate), 60-69 year-olds
(P=0.0021, Cohen’s d = 0.40, small), 70-79 year-olds (P=0.46, Cohen’s d = 0.12, trivial), females (P<10^{-9}, Cohen’s d = 1.37, large), and males (P<10^{-8}, Cohen’s d = 1.29, large) (Table 2).

For all subjects, average social jet lag was reduced during physical distancing when compared to baseline (P<10^{-18}, Cohen’s d = -1.93, large). When analyzed by cohort, average social jet lag was reduced during physical distancing when compared to baseline for 18-19 year-olds (P<10^{-17}, Cohen’s d = -2.23, very large), 20-29 year-olds (P<10^{-18}, Cohen’s d = -2.33, very large), 30-39 year-olds (P<10^{-18}, Cohen’s d = 1.87, very large), 40-49 year-olds (P<10^{-18}, Cohen’s d = -1.87, large), 50-59 year-olds (P<10^{-18}, Cohen’s d = -1.58, large), 60-69 year-olds (P<10^{-18}, Cohen’s d = -1.58, large), 70-79 year-olds (P<10^{-7}, Cohen’s d = -1.31, large), females (P<10^{-18}, Cohen’s d = -1.44, large), and males (P<10^{-18}, Cohen’s d = -1.95, large) (Table 2).
### Table 2. Objective sleep outcomes for age and gender cohorts as a function of time period.

| Variable                  | Time period | Outcomes |
|---------------------------|-------------|----------|
|                           | Baseline (M±SD) | Physical distancing (M±SD) | Difference (PD-BL) | Effect size (95% confidence limits) |
| **Sleep duration (hours)**|             |          |                  |                                |
| All subjects              | 6.92 ± 0.15 | 7.11 ± 0.14 | 0.19            | 1.31 (0.189, 0.191)           |
| 18-19 year-olds           | 7.17 ± 0.14 | 7.47 ± 0.16 | 0.30**          | 2.00 (0.282, 0.318)           |
| 20-29 year-olds           | 7.04 ± 0.11 | 7.29 ± 0.14 | 0.25**          | 1.99 (0.247, 0.253)           |
| 30-39 year-olds           | 6.92 ± 0.15 | 7.1 ± 0.14   | 0.18**          | 1.24 (0.177, 0.183)           |
| 40-49 year-olds           | 6.82 ± 0.19 | 6.99 ± 0.16  | 0.17**          | 0.97 (0.165, 0.175)           |
| 50-59 year-olds           | 6.75 ± 0.18 | 6.89 ± 0.16  | 0.14**          | 0.82 (0.133, 0.147)           |
| 60-69 year-olds           | 6.73 ± 0.15 | 6.79 ± 0.15  | 0.06*           | 0.40 (0.048, 0.072)           |
| 70-79 year-olds           | 6.61 ± 0.16 | 6.63 ± 0.17  | 0.02            | 0.12 (-0.014, 0.054)          |
| Females                   | 7.11 ± 0.17 | 7.33 ± 0.15  | 0.22**          | 1.37 (0.216, 0.224)           |
| Males                     | 6.86 ± 0.14 | 7.04 ± 0.14  | 0.18**          | 1.29 (0.182, 0.178)           |
| **Social jet lag (hours)**|             |          |                  |                                |
| All subjects              | 0.66 ± 0.14 | 0.44 ± 0.08  | -0.23           | -1.93 (0.219, 0.221)          |
| 18-19 year-olds           | 0.74 ± 0.18 | 0.36 ± 0.16  | -0.38**         | -2.23 (0.360, 0.400)          |
| 20-29 year-olds           | 0.88 ± 0.16 | 0.56 ± 0.11  | -0.32**         | -2.33 (0.317, 0.323)          |
| 30-39 year-olds           | 0.68 ± 0.14 | 0.46 ± 0.09  | -0.22**         | -1.87 (0.218, 0.222)          |
| 40-49 year-olds           | 0.53 ± 0.13 | 0.36 ± 0.08  | -0.17**         | -1.58 (0.167, 0.173)          |
| 50-59 year-olds           | 0.45 ± 0.13 | 0.29 ± 0.06  | -0.16**         | -1.58 (0.156, 0.164)          |
| 60-69 year-olds           | 0.34 ± 0.12 | 0.22 ± 0.05  | -0.12**         | -1.31 (0.112, 0.128)          |
| 70-79 year-olds           | 0.19 ± 0.16 | 0.1 ± 0.09   | -0.09**         | -0.69 (0.063, 0.117)          |
| Females                   | 0.61 ± 0.13 | 0.4 ± 0.09   | -0.21**         | -1.88 (0.207, 0.213)          |
| Males                     | 0.68 ± 0.14 | 0.45 ± 0.09  | -0.23**         | -1.95 (0.228, 0.232)          |

Notes: BL = baseline; PD = physical distancing; * = p-value <0.05; ** = p-value <0.001.
Fig 2. Daily average sleep duration aggregated by age cohort. Each cohort is plotted in a different color, indicated in the legend. Filled circles indicate Sundays; a vertical gray line separates baseline and physical distancing.

Exercise

Summaries of exercise behavior for age and gender cohorts are presented in Table 3 and Fig 3. On average, exercise frequency across all cohorts did not increase significantly during physical distancing when compared to baseline ($P=0.28$, Cohen’s $d = 0.28$, small). When analyzed by cohort, exercise frequency did not differ between baseline and physical distancing for 20-29 year-olds ($P=0.31$, Cohen’s $d = 0.02$, trivial), 30-39 year-olds ($P=0.09$, Cohen’s $d = 0.25$, small) and
males ($P=0.19$, Cohen’s $d = 0.15$, trivial). Exercise frequency significantly increased during physical distancing when compared to baseline for 18-19 year-olds ($P=0.005$, Cohen’s $d = -0.23$, small), 40-49 year-olds ($P=0.00009$, Cohen’s $d = 0.60$, moderate), 50-59 year-olds ($P<10^{-6}$, Cohen’s $d = 0.80$, moderate), 60-69 year-olds ($P<10^{-6}$, Cohen’s $d = 0.87$, moderate), 70-79 year-olds ($P=0.002$, Cohen’s $d = 0.48$, small), females ($P=0.001$, Cohen’s $d = 0.53$, small) (Table 3).

Table 3. Exercise frequency for age and gender cohorts as a function of time period.

| Cohort          | Exercise frequency (%) | Outcomes          |
|-----------------|------------------------|-------------------|
|                 | Baseline (M±SD)        | Physical distancing (M±SD) | Difference (PD-BL) | Effect size (95% confidence limits) |
| All subjects    | 61.6 ± 4.3             | 62.7 ± 4.2        | 1.1                | 0.26 (1.063, 1.137)               |
| Age (years)     |                        |                   |                    |                                   |
| 18-19 (%)       | 70.7 ± 8.8             | 68.9 ± 6.9        | -1.8*              | -0.23 (-2.733, -0.867)            |
| 20-29 (%)       | 63.6 ± 6.4             | 63.7 ± 5.2        | 0.1                | 0.02 (0.037, 0.237)               |
| 30-39 (%)       | 60.6 ± 4.6             | 61.7 ± 4.3        | 1.1                | 0.25 (1.012, 1.188)               |
| 40-49 (%)       | 60.4 ± 2.9             | 62.5 ± 4.0        | 2.1**              | 0.60 (2.006, 2.194)               |
| 50-59 (%)       | 60.7 ± 2.5             | 63.6 ± 4.5        | 2.9**              | 0.80 (2.742, 3.058)               |
| 60-69 (%)       | 60.7 ± 2.6             | 63.8 ± 4.3        | 3.1**              | 0.87 (2.809, 3.391)               |
| 70-79 (%)       | 59.3 ± 3.7             | 61.4 ± 4.9        | 2.1*               | 0.48 (1.200, 3.000)               |
| Sex             |                        |                   |                    |                                   |
| Females (%)     | 64.4 ± 5.3             | 67.1 ± 4.9        | 2.7*               | 0.53 (2.571, 2.829)               |
| Males (%)       | 60.7 ± 3.9             | 61.3 ± 4.0        | 0.6                | 0.15 (0.544, 0.656)               |

Notes: BL = baseline; PD = physical distancing; * = p-value <0.05; ** = p-value <0.001.

For exercise during physical distancing, individuals spent more time in HR zone 1 ($P=0.018$, Cohen’s $d = 0.57$, small), HR zone 4 ($P<10^{-7}$, Cohen’s $d = 0.56$, small), HR zone 5 ($P<10^{-10}$, Cohen’s $d = 1.44$, large), and HR zone 6 ($P<10^{-6}$, Cohen’s $d = 1.26$, large) when compared to baseline and spent less time during physical distancing in HR zone 2 ($P<10^{-10}$, Cohen’s $d = -1.04$, moderate) and HR zone 3 ($P<10^{-14}$, Cohen’s $d = -2.60$, large) compared to baseline (Table 4).
Fig 3. Percentage of each cohort active on WHOOP that logged an exercise session, by date. Each cohort is shown in a different color, indicated in the legend. Filled circles indicate Sundays; a vertical gray line separates baseline from physical distancing.
Table 4. Distribution of exercise intensity as a function of time period.

| HR Zone | Baseline (M±SD) | Physical distancing (M±SD) | Difference (PD-BL) | Effect size (95% confidence limits) |
|---------|----------------|---------------------------|--------------------|----------------------------------|
| Zone 1  | 12.3 ± 0.6     | 12.7 ± 0.8                | 0.4*               | 0.57 (0.399, 0.401)             |
| Zone 2  | 21.2 ± 1.0     | 20.3 ± 0.7                | -0.9**             | -1.04 (-0.901, -0.899)          |
| Zone 3  | 27.5 ± 0.5     | 26.2 ± 0.5                | -1.3**             | -2.60 (-1.301, -1.299)          |
| Zone 4  | 23.8 ± 0.9     | 24.3 ± 0.9                | 0.5**              | 0.56 (0.499, 0.501)             |
| Zone 5  | 13.5 ± 0.9     | 14.6 ± 0.6                | 1.1**              | 1.44 (1.099, 1.101)             |
| Zone 6  | 1.8 ± 0.2      | 2.0 ± 0.1                 | 0.2**              | 1.26 (0.200, 0.200)             |

Notes: BL = baseline; PD = physical distancing; * = p-value <0.05; ** = p-value <0.001.

Fig 4. Distribution of proportion of total exercise time spent in each heart rate zone by date. Each heart rate zone is shown in a different color, indicated by the legend. Filled circles indicate Sundays; the vertical gray line delineates between baseline and physical distancing.
Cardiovascular health

A summary of cardiovascular outcomes for age and gender cohorts are presented in Table 5. Average RHR was lower for all subjects during physical distancing when compared to baseline ($P<10^{-9}$, Cohen’s $d = -1.28$, large). When analyzed by cohort, average RHR was lower during physical distancing when compared to baseline for 18-19 year-olds ($P<10^{-9}$, Cohen’s $d = 1.29$, large), 20-29 year-olds ($P<10^{-9}$, Cohen’s $d = 1.14$, moderate), 30-39 year-olds ($P<10^{-9}$, Cohen’s $d = 1.19$, large), 40-49 year-olds ($P<10^{-10}$, Cohen’s $d = 1.32$, large), 50-59 year-olds ($P<10^{-13}$, Cohen’s $d = 1.62$, large), 60-69 year-olds ($P<10^{-14}$, Cohen’s $d = 1.82$, large), 70-79 year-olds ($P<10^{-13}$, Cohen’s $d = 1.53$, large), females ($P<10^{-12}$, Cohen’s $d = 1.43$, large), and males ($P<10^{-9}$, Cohen’s $d = 1.30$, large) (Table 5).

Average HRV was higher for all subjects during physical distancing when compared to baseline ($P=0.0004$, Cohen’s $d = -0.68$, moderate). When analyzed by cohort, average HRV was higher during physical distancing when compared to baseline for 18-19 year-olds ($P=0.02$, Cohen’s $d = -0.27$, small), 20-29 year-olds ($P=0.001$, Cohen’s $d = -0.59$, small), 30-39 year-olds ($P=0.0003$, Cohen’s $d = -0.69$, moderate), 40-49 year-olds ($P<10^{-6}$, Cohen’s $d = -0.89$, moderate), 50-59 year-olds ($P<10^{-11}$, Cohen’s $d = -1.36$, large), 60-69 year-olds ($P<10^{-16}$, Cohen’s $d = -1.97$, large), 70-79 year-olds ($P<10^{-4}$, Cohen’s $d = -0.76$, moderate), females ($P<10^{-6}$, Cohen’s $d = -0.96$, moderate), and males ($P=0.001$, Cohen’s $d = -0.60$, small) (Table 5).
Table 5. Cardiovascular outcomes for age and gender cohorts as a function of time period.

| Variable                        | Time period       | Outcomes       | Effect size                       |
|---------------------------------|-------------------|----------------|-----------------------------------|
|                                 | Baseline (M±SD)   | Physical distancing (M±SD) | Difference (PD-BL) | (95% confidence limits) |
| Resting heart rate (bpm)        |                   |                |                                  |
| All subjects                    | 55.3 ± 0.81       | 54.4 ± 0.63    | -0.9                             | -1.24 (-0.906, -0.894) |
| 18-19 year-olds                 | 53.6 ± 0.82       | 52.7 ± 0.55    | -0.9                             | -1.29 (-0.982, 0.818)  |
| 20-29 year-olds                 | 54.2 ± 1.02       | 53.2 ± 0.71    | -1.0                             | -1.14 (-1.021, -0.979) |
| 30-39 year-olds                 | 55.3 ± 0.85       | 54.4 ± 0.65    | -0.9                             | -1.19 (-0.915, -0.885) |
| 40-49 year-olds                 | 56.3 ± 0.64       | 55.5 ± 0.57    | -0.8                             | -1.32 (-0.816, -0.78)  |
| 50-59 year-olds                 | 56.5 ± 0.51       | 55.7 ± 0.48    | -0.8                             | -1.62 (-0.821, -0.779) |
| 60-69 year-olds                 | 56.2 ± 0.38       | 55.5 ± 0.39    | -0.7                             | -1.82 (-0.732, -0.668) |
| 70-79 year-olds                 | 54.9 ± 0.49       | 54.2 ± 0.42    | -0.7                             | -1.53 (-0.795, -0.605) |
| Females                         | 57.7 ± 0.69       | 56.8 ± 0.56    | -0.9                             | -1.43 (-0.916, -0.884) |
| Males                           | 54.6 ± 0.86       | 53.6 ± 0.66    | -1.0                             | -1.30 (-1.011, -0.989) |
| Heart rate variability (ms)     |                   |                |                                  |
| All subjects                    | 66.8 ± 2.19       | 68.1 ± 1.6     | 1.3                              | 0.68 (1.283, 1.317)    |
| 18-19 year-olds                 | 95.0 ± 3.78       | 95.8 ± 1.88    | 0.8                              | 0.27 (0.448, 1.152)    |
| 20-29 year-olds                 | 82.9 ± 2.99       | 84.4 ± 2.0     | 1.5                              | 0.59 (1.440, 1.560)    |
| 30-39 year-olds                 | 67.4 ± 2.14       | 68.7 ± 1.59    | 1.3                              | 0.69 (1.263, 1.337)    |
| 40-49 year-olds                 | 53.2 ± 1.35       | 54.3 ± 1.1     | 1.1                              | 0.89 (1.067, 1.133)    |
| 50-59 year-olds                 | 46.0 ± 1.06       | 47.4 ± 1.0     | 1.4                              | 1.36 (1.355, 1.445)    |
| 60-69 year-olds                 | 48.0 ± 0.9        | 49.8 ± 0.93    | 1.8                              | 1.97 (1.725, 1.875)    |
| 70-79 year-olds                 | 59.0 ± 3.15       | 61.2 ± 2.62    | 2.2                              | 0.76 (1.599, 2.801)    |
| Females                         | 66.3 ± 1.84       | 67.9 ± 1.46    | 1.6                              | 0.96 (1.558, 1.642)    |
| Males                           | 67.0 ± 2.31       | 68.2 ± 1.67    | 1.2                              | 0.60 (1.171, 1.229)    |

Notes: BL = baseline; PD = physical distancing; bpm = beats per minute; ms = milliseconds; * = p-value <0.05; ** = p-value <0.001.
**Fig 5.** Changes in RHR (top) and HRV (bottom) by date and age cohort. Each cohort is shown with a differently colored line as indicated in the legends. bpm = beats per minute; ms = milliseconds. Filled circles indicate Sundays; a gray vertical line separates baseline from physical distancing.
Discussion

The aim of this study was to detail changes in health related behavior and outcomes associated with the introduction of global physical distancing policies in response to the COVID-19 pandemic. A retrospective analysis of sleep and activity patterns covering January 1, 2020 through May 15, 2020 including 50,000 randomly selected WHOOP members ranging from age 18 to 80. Findings were divided into sleep, activity, and cardiovascular health categories and are discussed below.

Sleep

The primary sleep related findings were (1) sleep opportunity duration increased as a result of sleep opportunity onset shifting earlier during physical distancing (2) average sleep duration increased in all cohorts during physical distancing and (3) social jet lag – i.e., weekday-to-weekend variability of sleep opportunity onset and offset – decreased for all cohorts during physical distancing.

There was a large shift in all cohorts towards earlier sleep opportunity onset times during physical distancing when compared with baseline, but not to an equal extent. Older cohorts experienced progressively larger shifts in sleep opportunity onset times during physical distancing relative to baseline (Table 1). The oldest cohort, 70-79 year-olds, exhibited a shift 2.4 times greater than that exhibited by the youngest cohort, 18 and 19 year-olds. For the younger cohorts, 18-19 year-olds exhibited a similar sleep opportunity onset to the 20-29 year-olds during baseline, but during physical distancing, 20-29 year-olds observed a larger shift towards an earlier sleep opportunity onset (Table 1; Fig 1). This finding reflects the established differences in chronotype across age cohorts - younger individuals tend to have a late chronotype while older individuals skew towards early chronotypes [25].
In addition to exhibiting differences in the magnitude of average sleep onset shifts, Fig 1 highlights a change in the differences between weekend and weekday sleep opportunity onset (i.e., social jet lag) across all age groups. All age cohorts reduced social jet lag, with more extreme reductions seen in younger cohorts than in older ones (Table 2). The age group with the largest reduction was 18-19 year-olds. During baseline, this cohort averaged a 0.74 hour (i.e., 44 minutes) later sleep onset on weekends than on weekdays which was reduced during physical distancing to only 0.36 hours (i.e., 22 minutes). The smallest change, -0.08 hours (i.e., -5 minutes), was seen in the oldest cohort, 70-79 year-olds, who also had the least social jet lag in baseline – 0.19 hours (i.e., 11 minutes) (Fig 1).

Average nightly sleep duration was significantly higher during physical distancing than during baseline for all age cohorts (Fig 1). Younger cohorts obtained more sleep than older cohorts during baseline and increased their sleep by a greater percentage during physical distancing (Table 2; Fig 2). The 18-19 year-old cohort averaged 0.56 hours (i.e., 34 minutes) more sleep per night than the 70-79 year-olds during baseline but averaged 0.84 hours (i.e., 50 minutes) more sleep during physical distancing. Among gender cohorts, females slept an average of 0.25 hours (i.e., 15.0 minutes) more per night than males during baseline and increased their sleep during physical distancing by more than males (+13 minutes and +11 minutes, respectively; Table 2).

With larger shifts observed in sleep opportunity onset compared to sleep opportunity offset, it is reasonable to suggest that the extension of sleep opportunities and sleep were primarily achieved by going to bed earlier and not by sleeping in later. These findings suggest that physical distancing may have alleviated societal factors (e.g., work or academic commitments, commuting) that restrict sleep opportunity, allowing individuals to revert towards biological sleep/wake preferences. Practical applications can be made across all cohorts; however, the data highlight
important changes in behavior amongst the 18-19 year-old cohort. As mentioned above, individuals from this cohort typically have late chronotypes (i.e., their circadian drive for sleep initiates later in the night). However, they are often expected to fulfill academic or sport related commitments early in the morning - decreasing opportunity for sleep. Prior literature has demonstrated subjective and objective benefits associated with even minor extension to average sleep duration when sustained over time; a 2018 study by Lo et al. [26] showed that 10 minutes of extended sleep duration in secondary school students correlated with improved alertness and mental health. These findings show that despite their typically late chronotype, 18-19 year-olds will shift their sleep onset opportunity earlier if given the opportunity. In addition to improvements in cognition, sleep extensions have been shown to correspond with statistically significant reductions in systolic blood pressure [27].

Exercise

The primary exercise findings were that physical distancing restrictions resulted in (1) significant changes to the types of athletic activities performed, (2) significant increases in frequency of exercise across all cohorts, and (3) increases in exercise intensity across all cohorts. The changes in activities observed are consistent with adherence to bans on gatherings of more than 10 people and closures of athletic facilities such as fitness clubs and gyms. Coincidentally, athletic activities that are compliant to physical distancing appear to be those that also require high cardiovascular load (i.e., running, cycling). This is supported by our data highlighting a decrease in weightlifting, and increases in activities like running (Fig 6). This increase is likely due to the minimal equipment needs (e.g., pair of sneakers for running), and that individuals are likely to prioritize outdoor activities whilst confined to their homes for the majority of each day. Previous studies suggest
that engagement in new exercise modalities may reduce injury rates [28], improve athletic
performance and improve cardiovascular health [29, 30]. Therefore, alterations to training stimulus
(i.e., exercise modality), and the associated physiological adaptations, may be an unexpected side
effect of physical distancing restrictions.

![Chart showing percentage change from average for six popular exercise modalities]

**Fig 6.** Percentage of change from average for the six most popular exercise modalities. Each modality is shown with a differently colored line as indicated in the legends. Filled circles indicate Sundays; a gray vertical line separates baseline from physical distancing.

In addition to changes in exercise modalities performed, our data show that individuals exercised more frequently during physical distancing (Fig 3). All age cohorts except for the 18 and 19 year-olds increased their frequency of exercise during physical distancing as compared to
baseline. Again, this is likely due to increased flexibility during physical distancing to perform physical activity. In isolation of the impact of physical distancing on exercise frequency, a novel cyclical pattern with a 7-day period in exercise frequency is observed in most age cohorts in Fig 3. The cycle with highest amplitude is in 18 and 19 year-olds, the youngest cohort, with both the highest rates of exercise during the weekdays and the lowest rates of exercise on weekends. Again, this finding emphasizes the impact of professional and academic weekday commitments on exercise behavior.

In regard to the intensity of exercise, the highest three heart rate zones (collectively, 70-100% HRR) occupy a larger proportion of total exercise time during physical distancing than they did during baseline (Table 4). Distributions in relative time spent in heart rate zones 2 through 5 show a cyclical pattern with a 7-day period that is more pronounced during baseline than physical distancing; relatively more time is spent in zones 4, 5, and 6 on weekends, while more time is spent in zones 2 and 3 on weekdays. The differentiation between weekend and weekday heart rate zone distributions is less pronounced in all heart rate zones during physical distancing than it was during baseline. An increase in time spent in these higher heart rate zones may mean an increase in anaerobic training, which has been previously demonstrated to reduce RHR and improve endurance [31].

The present study highlights changes in exercise modality and increases in exercise frequency during physical distancing restrictions. Irrespective of societal influences, it is physiologically accurate to suggest that such changes to exercise behavior may improve health outcomes [32].
Cardiovascular Health

A major finding of this study was that average RHR decreased and HRV increased during physical distancing when compared to baseline for all age and gender cohorts (Fig 3). Both of these outcomes represent an improvement in cardiovascular health, which suggests that improved sleep and exercise behaviors may be conferring positive benefits on the WHOOP members analyzed.

Recent research has also demonstrated a relationship between social jet lag and HRV in which higher levels of social jet lag were associated with lower HRV [33]. These findings are consistent with the present study in which all cohorts experienced a reduction in social jet lag and increase in HRV during physical distancing.

Analysis of the baseline period shows expected moderate differences across age cohorts in which younger cohorts show signs of greater cardiovascular fitness than older cohorts. While it is well documented that HRV declines with age [34, 35], previous studies have demonstrated no age-related increase in RHR. For example, Kostis et al [36] found no relationship between age and RHR; this apparent discrepancy may be related to the small effect size and the relatively small datasets of previous studies. The demonstration here by analysis of 50,000 individuals that a statistically and practically significant increase in RHR with age occurs is a novel finding of this paper.
Conclusions

This is the first study to report on the sleep and exercise behavioral changes associated with COVID-19 related physical distancing mandates. By leveraging wearable technology, a unique analysis of large population cohorts both prior to and throughout the early stages of the COVID-19 pandemic were conducted. The findings suggest that meaningful changes have occurred to sleep and exercise patterns, which may have long-term consequences on the health and wellbeing of the population. While improved sleep and exercise patterns appear to be the mechanism for improved health outcomes during physical distancing, it is unclear which specific barriers were limiting these activities prior to physical distancing. It is reasonable to assume that decreases in business hours-based commitments (e.g., commuting) has previously limited the time devoted to exercise and sleep. Therefore, in the context of a post-pandemic society, increased flexibility in how business, academia and other professional endeavors are conducted (i.e., ability to work from home) may result in a healthier general population. The findings of this study should be interpreted with the sample demographic in mind – WHOOP subscribers may not demographically match the general population. It is reasonable to suggest that members of the WHOOP platform are more likely to be health-conscious and fitness-oriented than average. However, these data can be applied to a large population cohort that are seeking to engage more health-enhancing behavior despite professional commitments. Future research will be required as countries begin to reopen to investigate which behaviors are maintained, how these behaviors impact mental health, and if cohorts return to their previous behaviors.
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