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Examine the associations between perceived neighborhood conditions, physical activity, and mental health during the COVID-19 pandemic

Yong Yang a,*, Xiaoling Xiang b

a School of Public Health, University of Memphis, Memphis, TN, 38152, USA
b School of Social Work, University of Michigan, Ann Arbor, MI, 48109, USA

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ABSTRACT

This study examined how neighborhood conditions changed and how neighborhood conditions were associated with physical activity and mental health during the COVID-19 pandemic among Americans. The major outcomes were stratified by the neighborhood’s poverty and regression models were used to assess the associations between neighborhood conditions and their change during the pandemic and the outcomes of physical activity and mental health. The results show that low-poverty neighborhoods had more health-promoting neighborhood conditions before the outbreak and more positive changes during the outbreak. Health-promoting neighborhood conditions were associated with higher physical activity and moderate physical activity and lack of negative neighborhood conditions such as crime/violence and traffic were associated with a lower risk of mental health problems including loneliness, depression, and anxiety. Mental health problems were also significantly associated with the COVID-19 infection and death and household income level. Our findings suggest that it is plausible that the disparities of physical activity and mental health by neighborhood exacerbate due to the pandemic and people who living in socioeconomically disadvantaged neighborhoods bear increasingly disproportionate burden.

1. Introduction

The COVID-19 pandemic is continuing to shape human behaviors and the living environment. We are only beginning to understand the social, economic, and psychological disruptions resulting from the COVID-19 and the impacts of these disruptions on health and well-being. Although the disastrous consequences of COVID-19 are ubiquitous, some groups are being disproportionately affected. Ethnic minorities and low-income groups are particularly vulnerable to crises and may bear additional COVID-19’s burden due to their disadvantages in many social determinants of health such as employment and working status, underlying health issues, health care access, and living conditions such as the neighborhood environment (Lekfuangfu et al., 2020; Fothergill et al., 1999; Kirby, 2020).

It is well-established that the neighborhood environment affects many health outcomes and contributes to health disparities (Diez Roux and Mair, 2010; Gordon-Larsen et al., 2006). Among many neighborhood conditions, neighborhood poverty may be the primary factor that contributes to health disparity. First, neighborhoods with high poverty tend to have other negative conditions such as crime issues, heavy traffic, less access to recreational facilities, and neighborhood problems that were associated with mental disorders such as stresses, depressive symptoms, and anxiety (Echeverria et al., 2008; Moore et al., 2016). At the same time, PA, particularly recreational PA, was associated with access to facilities, neighborhood walkability, and esthetic attributes (Cerin et al., 2014; Cheval et al., 2019). Second, people living in high poverty neighborhoods are more likely to be ethnic minorities or with low socioeconomic status, and they are more likely to be disadvantaged in other social determinants (e.g., employment, health care) (Diez Roux and Mair, 2010; Do, 2009). Negative conditions in high poverty neighborhoods may interact with individual level’s factors and not only result in the disparity of health behaviors and outcomes directly but also create and reinforce social disparities that translate into health disparities indirectly.

The COVID-19 pandemic (referred to as the pandemic hereinafter) may also reduce people’s transport-related physical activity (PA) and recreational PA because people’s compromised mobility and the closure of non-essential businesses during the pandemic may reduce people’s access to recreational facilities such as gyms, supported by initial evidence across countries such as Iran, Italy, Japan, Thailand, and UK.
(Amini et al., 2020; Maugeri et al., 2020; Yamada et al., 2020; Kate-wongsan et al., 2020; Robinson et al., 2020). On the other hand, however, working from home, as a reaction to the pandemic for many people, may provide more time for people to engage in PA at home, yard, neighborhood, and nearby parks. In countries like the U.S., where recreational activities in the neighborhood and open space were not banned, people may engage more in running or walking in the neighborhood as an alternative PA. For example, a study in France and Switzerland found that people spent more time walking and moderate PA during the pandemic (Cheval et al., 2020).

Besides PA, mental health is another serious problem during the pandemic. Many countries have implemented social distancing, self-isolation, and stay-at-home orders. Although much needed to control the pandemic, these measures, together with other disruptions, have taken a toll on the people’s mental health such as the increased feeling of isolation, loneliness, anxiety, and depression, possibly due to stressors related to employment, financial concerns, risk of infections, and limited social interactions and recreational activities (Loades et al., 2020; Vindegaard and Benros, 2020).

PA, mental health, and neighborhood conditions may interact with each other during the pandemic. First, the maintenance of adequate PA is particularly important during the pandemic due to the well-established benefit of PA to mental health (Cooney et al., 2011; Callow et al., 2020), for example, through reducing stress (Campbell and Turner, 2018). Several studies had confirmed the protective effect of PA on mental health during the pandemic across countries such as Austria, Brazil, Italy, and the UK (Maugeri et al., 2020; Schuch et al., 2020; Pieh et al., 2020; Jacob et al., 2020). Second, neighborhoods with high social cohesion may help people to deal with stresses and better access to recreational facilities may provide more opportunities for PA. Third, people’s activities and behaviors may go back to change the neighborhood environment. For example, because of the travel limitation and closure of gyms and other recreational facilities, people may engage in higher PA in their yard, garden, and neighborhood and traffic may decrease (Hudda et al., 2020). Less traffic may also change the neighborhood environment. More walking and running in the neighborhood may increase social cohesion and increase the positive perception of the neighborhood and encourage more people to engage in PA thus positive feedback may be formed. However, in disadvantaged neighborhoods, things may go in the opposite direction. The neighborhood conditions may not supportive of PA despite people’s desire, and low socioeconomic status people may be more likely to meet financial hardship (e.g., loss of employment) and other challenges during the pandemic. Besides the multiple stressors, crime and violence may be further triggered and thus jeopardize people’s mental health status.

This study aimed to examine how neighborhood conditions changed during the pandemic and how neighborhood conditions were associated with PA and mental health during the pandemic. Specifically, we examined (1) if the neighborhoods with high poverty were more likely to have negative conditions (e.g., crime issues, heavy traffic) and observed negative changes (e.g., increased crime/violence) during the pandemic, (2) if positive neighborhood conditions and their positive changes during the pandemic were associated with higher PA, particularly recreational PA, and (3) if positive neighborhood conditions and their positive changes during the pandemic, as well as higher PA, were associated with to mental health outcomes.

2. Methods

2.1. Participants

We designed an online survey via Amazon Mechanical Turk (MTurk) (Keith et al., 2017), an online crowdsourcing platform. Participants were eligible if they (1) were residing in the USA and (2) had ≥ 90% approval ratings from previous MTurk tasks. We collected participants’ demographics, COVID-19 related experiences, perceived neighborhood conditions, PA, and mental health. Data were collected between April 27 and May 11, 2020. Each participant was compensated $0.30. The Institutional Review Board at the University of XXX approved this study.

2.2. Measures

First, participants reported the COVID-19 status of themselves and their family (if there were confirmed cases among family member, or if some family members were tested with negative results or untested symptoms), if any deaths of family members, friends, or colleagues from the COVID-19, the influence of the pandemic on their employment. Second, for neighborhood conditions, we collected social cohesion, neighborhood conditions, perceptions of change in the neighborhood since the pandemic. Third, we collected PA and several mental health outcomes including symptoms of depression, anxiety, and loneliness. Finally, a COVID-19 control measure at the state level was collected. Because people’s PA and mental health outcomes may be influenced by control measures such as social distancing and stay-at-home orders, we used a state-level measure of stay-at-home order (Moreland et al., 2020), a dichotomous value that depended on if a stay-at-home order was mandatory for all people in a state for more than 15 days during the April 2020 or not (our survey was conducted around the end of April 2020).

Social cohesion in the neighborhood. We used established social cohesion questions (Sampson et al., 1997; Bateman et al., 2017) to ask if people in the neighborhood are willing to help their neighbors, can be trusted, get along with one another, and share the same values, and whether this is a close-knit neighborhood. Each item is rated on a 5-point Likert scale, from strongly agree (5) to strongly disagree (1). The composite score ranges from 5 to 25, with a higher score indicating stronger neighborhood social cohesion.

Perceived neighborhood conditions were selected from the Neighborhood Environment Walkability Scale (Saelens et al., 2003), asked people to rate on a 5-point Likert scale to five conditions including whether there are sidewalks and attractive sights, whether crime and traffic make it unsafe or unpleasant to walk, and whether they see other people exercising in the neighborhood. Besides, participants rated their agreement on the changes in their neighborhood conditions due to COVID-19 on a 5-point Likert scale: (1) more social interactions, (2) more people walk or exercise in my neighborhood, (3) less crime/violence, (4) less traffic, and (5) improved aesthetics. Among the five items of change, the first (i.e., social interaction) corresponded to the social cohesion in the neighborhood, and the other four corresponded to the four neighborhood conditions aforementioned except sidewalk that was unlikely to change in short term. Furthermore, using participants’ residential zip-codes, we extracted urbanicity (urban, suburban, rural) from the Rural-Urban Commuting Area Codes (Department of Agricu, 2020) and the percent of families living below the poverty threshold within each zip-code based on the 2010 US Census.

Measures of PA were adapted from the International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003). We retained two domains of PA including (1) housework, house maintenance, and caring for family and (2) recreation, sport, and leisure-time PA (e.g., walk, aerobic, and running). The survey questions probed both the frequency and duration of any vigorous-intensity and moderate-intensity PA for more than ten continuous minutes in the past seven days. Following the IPAQ’s scoring protocol (www.ipaq.ki.se), we computed participants’ MET-min per week as the sum of vigorous PA (weighted as 8 METs), moderate PA (weighted as 4 METs), and walking (weighted 3.3 METs). The total PA of the two domains was classified into three different levels including low (<600 MET–minutes/week); moderate (≥600 MET–minutes/week) and high.

The three-item Loneliness Scale is a brief assessment of loneliness that includes three questions from the R-UCLA Loneliness Scale (Hughes et al., 2004). Participants answered how often they felt “lack companionship,” “left out,” and “isolated from others” on a 3-point Likert scale.
(hardly ever, some of the time, or often). A composite score ranges from 3 to 9, with a higher score corresponding to a higher level of loneliness.

**Depressive symptoms** were assessed using the Patient Health Questionnaire-2 items (PHQ-2) in combination with the PHQ-8 (Kroenke et al., 2010), an efficient way of screening for depression in both clinical care and in research (Levis et al., 2020). The PHQ-8 excludes the suicidality question from the PHQ-9 and is equivalent to the PHQ-9 in detecting depressive disorder (Wu et al., 2020). Participants first completed the PHQ-2 and, if scored ≥3, were then asked to complete the PHQ-8.

Assessment of anxiety symptoms involved the Generalized Anxiety Disorder-2 items (GAD-2), followed by the GAD-7 for those who scored ≥3 on the GAD-7 (Kroenke et al., 2010). The optional cutoff for PHQ-8 and the GAD-7 was ≥10 for identifying cases of major depression and anxiety, respectively (Spitzer et al., 2006; Kroenke et al., 2001).

### 2.3. Statistical analysis

First, descriptive statistics were conducted to summarize sample characteristics. The major outcomes such as neighborhood social cohesion, perceived neighborhood conditions, PA, and mental health outcomes were stratified by neighborhood poverty levels using T-test.

For neighborhood poverty and neighborhood conditions, that is, our first research question, a linear regression was conducted to assess the influence of neighborhood poverty on neighborhood social cohesion, and ten logistic regression models were conducted to assess the influence of neighborhood poverty on the five aforementioned neighborhood conditions, and the change of five neighborhood conditions during the pandemic, respectively.

For neighborhood conditions and PA, that is, the second research question, two linear regression models were used to assess the association of various neighborhood conditions and their changes during the pandemic with two PA outcomes including PA for household/yard, and PA for leisure, respectively.

For neighborhood condition, PA, and mental health outcome, that is, our third question, one linear regression was conducted to assess the associations between various neighborhood conditions and their changes as well as PA during the pandemic, with the loneliness score. And two logistic regression was conducted to assess the association between various neighborhood conditions and their changes as well as PA during the pandemic, with the odds ratios of having depression and anxiety, respectively.

All regression models were adjusted by demographic and socioeconomic covariates. All regression models except those for neighborhood social cohesion and neighborhood conditions were adjusted by the covariate of the state-level COVID-19 control measure.

Assumptions associated with logistic regression such as independence of errors, linearity, absence of multicollinearity, and lack of strongly influential outliers were checked. No outliers were found and no model adjustment was needed. Analyses were performed using SAS 9.4.

### 3. Results

As shown in Table 1, among the 2667 participants who completed the survey, the majority were men (54%), 18–34 years old (35%), and non-Hispanic White (67%). The mean age was 36.3 with a range between 18 and 89. Most had a college degree (63%) and lived in urban areas (84%). For most participants (74%), neither themselves nor their family members had COVID-19 related symptoms. Nevertheless, 6.5% of participants or their family members had positive COVID-19 test, and 13.2% had at least one COVID-19 death among family, friends, or colleagues. Over a third of participants worked from home or were taking paid time off due to the pandemic (35%), 18% permanently or temporarily lost their job, and 18% were working without a change in the nature or hours of work. About three fourth of participants were living in areas (84%). For most participants (74%), neither themselves nor their family members had COVID-19 related symptoms. Nevertheless, 6.5% of participants or their family members had positive COVID-19 test, and 13.2% had at least one COVID-19 death among family, friends, or colleagues. Over a third of participants worked from home or were taking paid time off due to the pandemic (35%), 18% permanently or temporarily lost their job, and 18% were working without a change in the nature or hours of work. About three fourth of participants were living in

| Category                  | Item                   | Percent |
|---------------------------|------------------------|---------|
| Gender                    | Female                 | 46.0    |
|                           | Male                   | 53.7    |
|                           | Others                 | 0.3     |
| Age                       | 18–34 years old        | 54.6    |
|                           | 35–59 years old        | 38.0    |
|                           | 60 years old and above | 7.4     |
| Race/ethnicity            | White                  | 67.2    |
|                           | Black                  | 8.4     |
|                           | Asian                  | 11.5    |
|                           | Hispanic               | 11.2    |
|                           | Others and mixed       | 1.7     |
| Educational attainment    | High school and below  | 8.1     |
|                           | Above high school and below bachelor | 29.3 |
|                           | Bachelor and above     | 62.5    |
| Household income level    | Less than $24,999      | 15.7    |
|                           | $25,000 to $49,999     | 22.0    |
|                           | $50,000 to $74,999     | 23.9    |
|                           | $75,000 to $99,999     | 16.7    |
|                           | $100,000 or more       | 22.8    |
| Neighborhood poverty level| Low level (<5%)        | 13.2    |
|                           | Middle level (5% and <20%) | 68.3 |
|                           | High level (≥20%)      | 18.5    |
| * Urbanization level      | Urban                  | 84.3    |
|                           | Suburban               | 11.9    |
|                           | Rural                  | 3.8     |
| Covid-19 status for self and family | Some confirmed infections | 6.5 |
|                           | Tested with negative results or untested symptoms | 19.6 |
|                           | No symptom             | 73.9    |
| Employment change due to the COVID-19 pandemic | Work without change | 17.6 |
|                           | No job before the pandemic | 20.4 |
|                           | Lost job or it was closed temporarily | 18.0 |
|                           | Work from home before the pandemic | 9.2 |
|                           | Work from home or be paid for time off | 34.6 |
| Death from COVID-19 among family member, friends, or colleagues | Yes | 13.2 |
|                           | No                     | 86.8    |
| Family size               | 1                      | 14.4    |
|                           | 2                      | 26.9    |
|                           | 3                      | 22.0    |
|                           | 4                      | 22.2    |
|                           | ≥5                     | 14.5    |
| Having stay home order at the state level | No | 24.4 |
|                           | Yes                    | 75.6    |

Notes: * the urbanization level was classified using the rural-urban commuting area (RUCA) codes [39] from the home address’ zip-codes, as urban (RUCA code 1). Suburban (RUCA codes 2–6), and rural (RUCA codes 7–10).

Table 2 shows the major outcomes and how they are stratified by participants’ neighborhood poverty level at the zip code level (here, neighborhood poverty was categorized into three levels). Overall, the majority of the participants had a positive perception of all five neighborhood conditions. As mental health outcomes, the mean loneliness score was 5.3 (SD = 1.9) and more than one-third of the participants had clinically significant anxiety (34.3% with PHQ-8 ≥ 10) and depressive symptoms (36.2% with GAD-7 ≥ 10). For disparity, a lower poverty level of the neighborhood was associated with high social cohesion, fewer sidewalks, more attractive sights, more people exercise, less crime/violence, and less traffic. For most neighborhood conditions, the differences between low and high poverty neighborhoods were between small and medium according to the effect size (Sullivan, 2012 #6514).

During the pandemic, people living in neighborhoods with a low poverty level were more likely to observe increased walking, increased social interactions, increased aesthetics, and decreased traffic. It was the
people living in neighborhoods with a high poverty level were more likely to see a decreased crime and violence. People living in neighborhoods with a low poverty level tend to engage lower PA for household/yard but higher PA for leisure compared with those living in neighborhoods with a high poverty level. The three mental health outcomes were not significantly different by neighborhood poverty.

Table 3 shows the association between neighborhood poverty and neighborhood conditions and their change over the pandemic. Overall, neighborhoods with higher poverty were more likely to have lower social cohesion, have sidewalks, with crime and violence as barriers to walking. Neighborhoods with lower poverty were more likely to have attractive sights, see people exercise around the neighborhood, and observe more people walk or exercise, more social interactions, and increased aesthetics over the pandemic. Compared with males, females were more likely to perceived neighborhood conditions as positive and observe more people walk or exercise during the pandemic. Older age was associated with more likely to perceive neighborhood conditions as positive but less likely to observe more people walk or exercise and more social interactions in the neighborhood over the pandemic. Compared with White, minorities were more likely to live in a neighborhood with sidewalks but having crime, violence, and traffic as barriers to walking. At the same time, minorities were more likely to observe decreased crime or violence over the pandemic. Educational attainment and household income level were positively associated with most neighborhood conditions and their positive changes except higher educational attainment were associated with an increased possibility of perceiving crime, violence, and traffic as barriers to walking. Compared with urban areas, people living in suburban or rural areas were more likely to perceive their conditions as negative and perceive positive change over the pandemic. People living in states that had a stay home order were more likely to observe more people walk or exercise in the neighborhood.

Table 4 shows the results from regression analyses for two PA outcomes. Increased age was associated with higher PA for household/yard but lower PA for leisure. Higher educational attainment and living in rural areas were associated with higher PA for both purposes. As the influence of neighborhood conditions, higher neighborhood social, without crime, violence, and traffic as barriers of walking, and increased social interactions and aesthetics during the pandemic were associated with higher PA for both purposes. Some neighborhood conditions were only associated with PA for a certain purpose. For example, attractive sights in the neighborhood and increased walking were associated with PA for leisure but not with PA for household/yard. People living in states that had a stay home order were more likely to increase their PA for household/yard.

Table 5 shows the results from regression analyses for the three mental health outcomes. Briefly, age was inversely associated with mental health. The loneliness score and the odds of depression and anxiety were negatively associated with family income but positively associated with family size. Having confirmed cases of COVID-19 in the family were associated with increased loneliness score and more than double the risk of anxiety and depression, and the death from COVID-19 among family members, friends, or colleagues also increased the risks for depression and anxiety. Among neighborhood conditions, social cohesion, crime, and traffic issues were significantly associated with all mental health outcomes. Higher neighborhood social cohesion was associated with a lower score of loneliness, and lowers odds of depression and anxiety, whereas crime/violence and traffic issues in the neighborhood were associated with a higher score of loneliness, and higher odds of depression and anxiety. Almost all neighborhood condition changes over the pandemic were not associated with any mental health outcomes except the decrease in traffic was associated with increased loneliness scores. Compared with low PA, moderate PA was associated with a lower risk of all three mental health outcomes, but high PA was not. The risk of having mental health problems was not significantly different between people who were living in states that had a stay home order and those who were not.

4. Discussions

To our knowledge, this was the first study that examined perceived neighborhood conditions and their change, PA, and mental health outcomes during the pandemic in the US. One advantage of this study is the use of both perceived and objective measures of multiple neighborhood conditions and their changes since the pandemic, as well as multi-domains of PA assessments and robust mental health measures. Overall, the findings are consistent with our three hypotheses, as our results showed that low-poverty neighborhoods had more health-promoting

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**Table 2**

Major outcomes stratified by residential neighborhood poverty level.

| Neighborhood social cohesion | All | Neighborhood poverty level | Effect size of the difference between people living in low and high poverty neighborhoods* |
|-----------------------------|-----|-----------------------------|----------------------------------------------------------------------------------|
|                             |     | Low (<5%), N = 343          | Medium (≥5% and <20%), N = 1768                                                  | High (≥20%), N = 479                                                                 |
| Neighborhood conditions, %  |     |                             |                                                                                  |                                                                                  |
| With sidewalks              | 17.6| 18.2                        | 17.6                                                                             | 17.3                                                                             | 0.02                                                                              |
| With attractive sights      | 65.2| 61.5                        | 64.9                                                                             | 68.9                                                                             | –0.16                                                                             |
| See people exercise         | 61.2| 71.7                        | 61.1                                                                             | 54.1                                                                             | 0.36                                                                              |
| Crime and violence as a     | 73.9| 79.3                        | 75.4                                                                             | 65.6                                                                             | 0.31                                                                              |
| barrier to walking          | 14.2| 12.5                        | 12.5                                                                             | 19.4                                                                             | –0.20                                                                             |
| Traffic is a barrier to     | 19.6| 16.0                        | 18.6                                                                             | 23.6                                                                             | –0.19                                                                             |
| walking                     |     |                             |                                                                                  |                                                                                  |                                                                                  |
| Neighborhood change during  |     |                             |                                                                                  |                                                                                  |                                                                                  |
| COVID-19 pandemic, %        |     |                             |                                                                                  |                                                                                  |                                                                                  |
| Increased walking           | 63.2| 70.3                        | 64.9                                                                             | 53.7                                                                             | 0.34                                                                              |
| Increased social interactions| 30.8| 33.2                        | 30.5                                                                             | 29.0                                                                             | 0.09                                                                              |
| Decreased crime/violence    | 35.0| 32.7                        | 33.9                                                                             | 38.2                                                                             | –0.12                                                                             |
| Decreased traffic           | 62.5| 67.6                        | 61.4                                                                             | 62.4                                                                             | 0.11                                                                              |
| Increased aesthetics        | 44.8| 46.9                        | 44.7                                                                             | 40.9                                                                             | 0.12                                                                              |
| Physical activity (min)     |     |                             |                                                                                  |                                                                                  |                                                                                  |
| PA for household/yard       |     |                             |                                                                                  |                                                                                  |                                                                                  |
| Low (≤5%), N = 343          | 223.4| 208                         | 223.4                                                                             | 222.2                                                                             | –0.11                                                                             |
| Medium (≥5% and <20%), N = 1768| 239.2| 260.7                       | 236.3                                                                             | 228.3                                                                             | 0.14                                                                              |
| High (≥20%), N = 479        |     |                             |                                                                                  |                                                                                  |                                                                                  |
| Percent of those having     |     |                             |                                                                                  |                                                                                  |                                                                                  |
| depression (PHQ-8 ≥ 10)     |     |                             |                                                                                  |                                                                                  |                                                                                  |
| Low (≤5%), N = 343          | 34.3| 35.6                        | 33.9                                                                             | 33.2                                                                             | 0.05                                                                              |
| Medium (≥5% and <20%), N = 1768| 36.2| 36.4                        | 35.9                                                                             | 36.3                                                                             | 0.002                                                                             |
| High (≥20%), N = 479        |     |                             |                                                                                  |                                                                                  |                                                                                  |
| Mental health               |     |                             |                                                                                  |                                                                                  |                                                                                  |
| Loneliness score            |     |                             |                                                                                  |                                                                                  |                                                                                  |
| Low (≤5%), N = 343          | 5.3 | 5.1                         | 5.3                                                                             | 5.2                                                                             | –0.05                                                                             |
| Medium (≥5% and <20%), N = 1768| 34.3| 35.6                        | 33.9                                                                             | 33.2                                                                             | 0.05                                                                              |
| High (≥20%), N = 479        |     |                             |                                                                                  |                                                                                  |                                                                                  |
| Percent of those having     |     |                             |                                                                                  |                                                                                  |                                                                                  |
| anxiety (GAD-7 ≥ 10)        |     |                             |                                                                                  |                                                                                  |                                                                                  |
| Low (≤5%), N = 343          | 36.2| 36.4                        | 35.9                                                                             | 36.3                                                                             | 0.002                                                                             |
| Medium (≥5% and <20%), N = 1768| 36.2| 36.4                        | 35.9                                                                             | 36.3                                                                             | 0.002                                                                             |
| High (≥20%), N = 479        |     |                             |                                                                                  |                                                                                  |                                                                                  |

Notes: * Effect size = (mean of low poverty neighborhoods – mean of high poverty neighborhoods) divided by the pooled standard deviation of all participants. The effect size is classified as small (0.2), medium (0.5), and large (0.8) (Sullivan, 2012 #6514). Boldface indicates the effect size was larger than small.
### Table 3
Results of regression models: perceived neighborhood conditions and their changes over the COVID-19 pandemic

#### (a) Neighborhood social cohesion.

| Gender | Male (ref) | 0 | Female | −0.06 (−0.37,0.25) | Others | −4.44(−7.06,−1.81)** |
|--------|-----------|---|--------|-------------------|-------|----------------------|
| Age    |            |   |         |                   |       |                      |
| Race/ethnicity | White (ref) | 0 | Black  | 0.28 (0.29,0.86)  |       |                      |
|         | Asian      | −0.67(−1.16,−0.17)** |       |                   |       |                      |
|         | Hispanic   | 0.25 (0.25,0.76)  |       |                   |       |                      |
|         | Others and mixed | 0 (−1.19,1.19) |       |                   |       |                      |
| Education attainment |         |   |         |                   |       |                      |
| Household income |         |   |         |                   |       |                      |
| Urbanization level | Urban (ref) | 0 | Suburban | 0.47 (0.01,0.95)  |       |                      |
|                | Rural     | 0.64 (−0.17,1.46) |       |                   |       |                      |
| Neighborhoods poverty (%) |       |   |         |                   |       | −0.02(−0.03,0)**    |

#### (b) Neighborhood conditions.

| Gender | Male (ref) | 1 | Female | 1.5 (1.27,1.77)** | Others | 1.33 (0.32,5.46) |
|--------|-----------|---|--------|-------------------|-------|-----------------|
| Race/ethnicity | White (ref) | 1 | Black  | 0.79 (0.62,1.01)  |       | 0.53(0.41,0.69) |
|         | Asian      | 0.53(0.35,0.81) |       |                   |       | 0.28(0.19,0.43) |
|         | Hispanic   | 1.50(0.40,5.71) |       |                   |       | 0.77(0.58,1.02) |
|         | Others and mixed | 1.2 (0.64,2.25) |       |                   |       | 0.71(0.37,1.36) |
| Educational attainment | 1.5 (1.12,1.47)** |   |         |                   |       | 1 (1.0,1.0) |
| Household income level | 1.04 (0.97,1.1) |   |         |                   |       | 1.15(1.08,1.22) |
| Urbanization level | Urban (ref) |   | Suburban | 0.35 (0.28,0.45)** |       | 0.79 (0.62,1.01) |
|                | Rural     | 0.30(0.20,0.46)** |       |                   |       | 0.53(0.41,0.69) |
| Neighborhoods poverty (%) | 1.01(1.01,1.02) |   |         |                   |       | 0.99(0.98,1.0)** |

#### (c) Change of neighborhood conditions.

| Gender | Male (ref) | 1 | Female | 1.5 (1.27,1.77)** | Others | 1.33 (0.32,5.46) |
|--------|-----------|---|--------|-------------------|-------|-----------------|
| Age    | 18-34 (ref) | 0.99 (0.99,1.0)** |       | 1 (0.99,1.01)  |       | 1.01 (1.01,1.0) |
| Race/ethnicity | White (ref) | 1 | Black  | 0.80 (0.59,1.09)  |       | 0.77 (0.59,1.03) |
|         | Asian      | 0.69 (0.53,0.9)** |       | 0.77 (0.59,1.03) |       | 1.64 (0.69,12.4) |
|         | Hispanic   | 0.9 (0.69,1.17) ** |       | 1.47(1.13,1.91) |       | 1.81(1.42,3.25) ** |
|         | Others and mixed | 0.8 (0.43,1.5) |       | 1.64 (0.89,3.05) |       | 1.34 (0.72,2.49) ** |

(continued on next page)
neighborhood conditions before the pandemic and more positive changes since the pandemic; health-promoting neighborhood conditions were associated with higher PA, and moderate PA and lack of negative neighborhood conditions such as crime/violence and traffic were associated with a lower risk of mental health problems. Taken together, these findings suggest that it is highly plausible that the disparities of PA and mental health by neighborhood exacerbate due to the pandemic and people who living in socioeconomically disadvantaged neighborhoods bear an increasingly disproportionate burden.

The disparity of neighborhood conditions may contribute to the disparity of health behaviors. As our results show people living in low-poverty neighborhoods had higher PA for leisure. Compared with high

### Table 4

Results of linear regression models: the adjusted mean of PA.

|                      | Hours of PA for household/yard | Hours of PA for leisure |
|----------------------|--------------------------------|-------------------------|
| Gender               |                                |                         |
| Male (ref)           | 0                              | 0                       |
| Female               | 0.12 (-0.14, 0.38)             | -0.51 (-0.79, -0.22)**  |
| Others               | -1.37 (-3.57, 0.83)            | -1.19 (-3.55, 1.16)     |
| Age                  | 0.01 (0.03)**                   | -0.02 (-0.03, 0)**      |
| Race/ethnicity       |                                |                         |
| White (ref)          | 0                              | 0                       |
| Black                | 0.04 (-0.45, 0.53)             | -0.33 (-0.85, 0.2)      |
| Asian                | -0.88 (-1.31, -0.46)**         | -0.17 (-0.63, 0.28)    |
| Hispanic             | 0.88 (0.45, 1.3)**             | 0.83 (0.38, 1.29)**     |
| Others and mixed     | 1.31 (0.32, 2.3)**             | 0.25 (0.81, 1.31)       |
| Educational attainment |                                 |                         |
| Urban (ref)          | 0.03 (-0.18, 0.24)             | 0.48 (0.25, 0.7)**      |
| Suburban             | 0.07 (-0.03, 0.17)             | 0.08 (-0.03, 0.19)      |
| Rural                | 1.74 (1.05, 2.43)**            | 0.93 (0.19, 1.68)*      |
| Household income level |                                |                         |
| Urban (ref)          | 0.01 (0.03)                    | -0.01 (-0.02, 0.01)     |
| Suburban             | 0.35 (-0.06, 0.76)             | 0.06 (-0.38, 0.5)       |
| Rural                | 1.74 (1.05, 2.43)**            | 0.93 (0.19, 1.68)*      |
| Neighborhoods poverty (%) |                                |                         |
| Rural                | 0.01 (0.03)                    | -0.01 (-0.02, 0.01)     |
| Having stay home order at the state level | 0.34 (0.04, 0.64)* | 0.13 (-0.19, 0.45) |
| Neighborhood social cohesion | 0.11 (0.07, 0.14)** | 0.08 (0.05, 0.12)** |
| Change of neighborhood conditions |                      |                         |
| Has sidewalks        | -0.35 (-0.65, 0.05)*           | 0.11 (-0.21, 0.43)      |
| Has attractive sights| -0.01 (-0.31, 0.29)            | 0.39 (0.07, 0.71)*      |
| See people exercise around neighborhood | -0.04 (-0.39, 0.31) | 0.14 (0.24, 0.52) |
| Crime and violence is a barrier of walking | -1.49 (-1.92, -1.07)** | -1.31 (-1.77, -0.85)** |
| Traffic is a barrier of walking | -0.46 (-0.85, -0.1)* | -0.69 (-1.09, -0.3)* |
| Increased social interaction | 0.52 (0.21, 0.84)** | 0.64 (0.31, 0.97)** |
| Increased walking    | 0.13 (-0.18, 0.44)             | 0.79 (0.46, 1.12)**     |
| Decreased crime      | 0.28 (-0.02, 0.58)             | -0.14 (-0.47, 0.19)     |
| Decreased traffic    | 0.38 (0.09, 0.66)**            | 0.04 (-0.26, 0.35)      |
| Increased Aesthetics | 0.77 (0.48, 1.06)**            | 0.51 (0.20, 0.82)**     |

Note: boldface indicates statistical significance, with * for p < 0.05, and ** for p < 0.01.

Education attainment is coded into three levels: 1 for high school and below; 2 for above high school and below bachelor; and 3 for bachelor and above.

Household income level is coded into five levels: 1 for less than $24,999; 2 for $25,000 to $49,999; 3 for $50,000 to $74,999; 4 for $75,000 to $99,999; and 5 for $100,000 or more.

Urbanization level is categories using the rural urban commuting area (RUCA) codes [39] from the home address’ zip-codes, as three levels including (1) urban (RUCA code 1); (2) suburban (codes 2–6); and (3) rural (codes 7–10).
Table 5: Results of regression models: the adjusted mean of loneliness score, and the odds ratios of depression and anxiety.

| Independent Variables | Adjusted mean difference of loneliness score | Odds ratio of having depression (PHQ-8 ≥ 10) | Odds ratio of having anxiety (GAD-7 ≥ 10) |
|-----------------------|-------------------------------------------|-------------------------------------------|------------------------------------------|
| **Gender**            |                                           |                                           |                                          |
| Male (ref)            | 0                                         | 1                                        | 1                                        |
| Female                | 0.08 (-0.06, 0.22)                        | 1.17 (0.97, 1.42)                        | 1.42 (1.18, 1.71)**                     |
| Others                | -0.04 (-1.21, 1.12)                       | 4.52 (0.86, 23.84)                       | 2.52 (0.52, 10.23)                      |
| **Age**               |                                           |                                           |                                          |
| White (ref)           | 0                                         | 1                                        | 1                                        |
| Black                 | -0.17 (-0.43, 0.09)                       | 0.79 (0.55, 1.12)                       | 0.76 (0.54, 1.07)                      |
| Asian                 | 0.09 (0.13, 0.32)                         | 1.27 (0.95, 1.69)                       | 1.03 (0.77, 1.38)                      |
| Hispanic              | -0.02 (-0.25, 0.21)                       | 1.07 (0.81, 1.44)                       | 1.17 (0.88, 1.56)                      |
| Others and mixed      | 0.34 (-0.18, 0.86)                        | 2.47 (1.29, 4.74)**                     | 2.64 (1.38, 5.06)**                    |
| **Race/ethnicity**    |                                           |                                           |                                          |
| White (ref)           | 0                                         | 0.92 (0.75, 1.13)                       | 1.31 (0.84, 2.05)                      |
| Black                 | -0.17 (-0.43, 0.09)                       | 0.79 (0.55, 1.12)                       | 0.76 (0.54, 1.07)                      |
| Asian                 | 0.09 (0.13, 0.32)                         | 1.27 (0.95, 1.69)                       | 1.03 (0.77, 1.38)                      |
| Hispanic              | -0.02 (-0.25, 0.21)                       | 1.07 (0.81, 1.44)                       | 1.17 (0.88, 1.56)                      |
| Other and mixed       | 0.34 (-0.18, 0.86)                        | 2.47 (1.29, 4.74)**                     | 2.64 (1.38, 5.06)**                    |
| **Education attainment** |                                         |                                           |                                          |
| Low (ref)             | 0                                         | 1                                        | 1                                        |
| Moderate              | -0.36 (-0.55, -0.16)**                    | 0.69 (0.53, 0.88)**                     | 0.76 (0.59, 0.97)**                     |
| High                  | -0.17 (-0.40, 0.06)                       | 1.03 (0.76, 1.39)                       | 1.14 (0.85, 1.53)                      |

Note: boldface indicates statistical significance, with * for p < 0.05, and ** for p < 0.01.

- **Education attainment** is coded into three levels: 1 for high school and below; 2 for above high school and below bachelor; and 3 for bachelor and above.
- **Household income** is coded into five levels: 1 for less than $24,999; 2 for $25,000 to $49,999; 3 for $50,000 to $74,999; 4 for $75,000 to $99,999; and 5 for $100,000 or more.
- **Urbanization level** is categorized using the rural urban commuting area (RUECA) codes [39] from the home address zip-codes, as three levels including (1) urban (RUECA code 1); (2) suburban (codes 2–6); and (3) rural (codes 7–10).
- **Neighborhood conditions** are categorized using the rural urban commuting area (RUECA) codes [39] from the home address zip-codes, as three levels: (1) urban (RUECA code 1); (2) suburban (codes 2–6); and (3) rural (codes 7–10).

Poverty neighborhoods, neighborhoods with a low poverty tended to have more attractive sights, less crime and violence, and less traffic, all of which are health-promoting environmental characteristics. However, the low-poverty neighborhood also had fewer sidewalks. In the U.S., poor neighborhoods tend to be centered in urban downtown areas with sidewalks, whereas more affluent neighborhoods tend to be in suburban areas with few sidewalks (Kneebone et al., 2011). The presence of sidewalks and the higher land use density and mix in such neighborhoods allow people living there to walk for transportation purposes as a resource of PA. Importantly, during the pandemic, neighborhoods with lower poverty were more likely to observe positive changes in all conditions except the crime. High poverty neighborhoods were more likely to observe a decrease in crime or violence, may because crime and violence were already low in neighborhoods with low poverty thus had no room to decrease. For all three mental health outcomes, we did not find a consistent disparity pattern by neighborhood poverty although all three mental health outcomes were significantly associated with household income levels. This indicates that the influence of neighborhood conditions to mental health outcomes is not stronger comparing with PA. Compared with PA, the influence of neighborhood conditions on mental health may involve multiple complicated pathways (Cutrona et al., 2006).
As we discussed above, the change of PA was unlikely to be evenly distributed, and people living in low-poverty neighborhoods not only engage more walk for leisure but also more likely to increase their walk for leisure during the pandemic. That is, the disparity of walk for leisure may increase. This indicated people lost their access to PA facilities either voluntary or involuntary. Exercising at home or neighborhood may help to alleviate the need for PA temporarily but maybe not a feasible solution for everyone. For example, people living in low poverty neighborhoods may not be able to have PA in their neighborhoods with safety concerns. Some PAs (e.g., swimming) could only be engaged in gyms. PA in groups may be particularly important to some segments such as youth. The United Nations released a policy brief to encourage (The impact ofD-19 on, 2020) governments to provide clubs and other sports organizations with safety and health guidance and make sure safe working conditions for future sports events and PA activities. At the same time, governments should collaborate with stakeholders such as health services and schools to support PA at home, for example, online resources to support PA.

The prevalence of depression and anxiety in our study (36.2% and 34.3%, respectively) were substantially higher than the estimated 8% in the US adult population before the pandemic (Brody et al., 2018). A synthesis of 28 studies on mental health symptoms in the COVID-19 pandemic reported that the symptoms of anxiety and depression ranged from 16 to 28% across studies (Rajkumar, 2020). Studies of general populations under “lockdown” and high-risk populations, rates of mental health symptoms were even higher. For example, in a study of frontline health care workers in Wuhan, China, 50.4% of the participants reported symptoms of depression and 44.6% anxiety as assessed using PHQ-9 and GAD-7 respectively (Lai et al., 2020). Our survey data were collected from general US adults between April 27 and May 11, 2020, during which time many US states and districts implemented pandemic lockdown measures. Our estimates, therefore, were slightly higher than the average from the recent literature synthesis but lower than those reported among frontline health workers in the early epicenter for COVID-19.

Larger family size was associated with a higher risk of depression and anxiety in our study. Since the pandemic took hold in the U.S., many schools are closed, and workers have transitioned to working from home. The sudden increase in time spent together within a common living space may create stresses and conflicts within families. Studies have long highlighted the importance of family relationship quality for mental health. For instance, tensions with mothers, siblings, and spouses may lead to depressive symptoms in middle-aged U.S. adults (Gilligan et al., 2017). Left unresolved, these family conflicts create risk for physical aggression and domestic violence. This finding highlights a need for resources to help families manage conflict during periods of home confinement. Personal losses due to COVID-19-related death was a significant risk factor for depression and anxiety, increasing these disorders by 61% and 42%, respectively. The death of a loved one is highly impactful and sometimes leads to prolonged grief disorder. Loss and grief may be particularly challenging in contexts with widespread community loss and a lack of familiar ways of grieving (e.g., limiting the size of funerals or ban funerals altogether).

This study has several limitations. First, we used a cross-sectional design and measured the change of neighborhood using retrospective recall, which is subject to recall bias. PA and mental health outcomes were not assessed before the pandemic, making it difficult to conclude the direction of the relationship. Future studies with repeated measures are planned to further examine changes in health behaviors and health status associated with the pandemic. Besides, our study sample was recruited from a crowdsourcing platform. Study participants tended to be younger and highly educated compared to the average US adult. Nevertheless, an online crowdsourcing marketplace has become increasingly popular for conducting surveys and remains an efficient way of gathering timely data from a large segment of the population to aid public health decision-making. Additionally, to assess the

association between PA and mental health outcomes, PA was categorized into three levels. Such categorization may be arbitrary and cannot precisely reflect their association.

Our findings may provide evidence to support policies or programs that aimed to improve the resources and facilities in disadvantaged neighborhoods and communities and tailor to the needs of vulnerable populations. For example, considering the interactions between mental health and PA, creative interventions that may address multiple issues simultaneously are needed.

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