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Unequal impact of the COVID-19 pandemic on mental health: Role of the neighborhood environment

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ABSTRACT

The COVID-19 pandemic has taken a significant toll on people's mental wellbeing. Few studies have investigated how the neighborhood environment might help to moderate the mental health impact in a natural disaster context. We aim to investigate the unequal impact of the pandemic on mental health between different population groups, and the role of the neighborhood environment in alleviating this impact. We collected survey data (n=2,741) on mental health, neighborhood environment, and pandemic-related behaviors in Beijing metropolitan region between July 10 and 28, 2020, and then applied the partial proportional odds model. Overall, we found that the pandemic has disproportionately affected the lower-income people. The lower-income residents experienced a greater psychological impact than the higher-income residents. We further found that distance to an urban park was a key built environment variable that moderates mental health impact. Residents who lived near urban parks were 4.2 to 4.6% less likely to report an increase in negative emotions, and therefore are more resilient to the mental health impact. In addition to the built environment, a cohesive neighborhood environment may have also helped to mitigate the negative mental health impacts. These findings can inform planning policies that aim to promote healthy and resilient communities.

1. Introduction

The COVID-19 pandemic has turned into a global public health disaster, significantly impacting people's quality of life. To prevent the spread of COVID-19, many cities and regions have implemented various travel restrictions and closures. Although these efforts have been effective in containing the diseases, they have severely limited people's ability to engage in important social activities such as work, shopping, socializing, and leisure. In addition, people have faced more stressors during the pandemic, such as social isolation due to the lockdown, fear of contracting the virus, domestic violence, racial and geographical discrimination, and financial crises due to underemployment and unemployment (Bodrud-Doza et al., 2020; Moore et al., 2021). There are all factors that increase the risk of mental health problems (Adhanom Ghebreyesus, 2020). In particular, residents in megacities may have experienced a greater mental health impact than those in small towns and rural areas (Menculini et al., 2021; Ziebold and Mari, 2020). Big cities have high population density and relatively crowded housing, leading to a high risk of infection and strict lockdown policy (Ren et al.,

2020). Also, many public transit systems in megacities have been disrupted as a result of the pandemic (Cui et al., 2022; Hasselwander et al., 2021). This has increased travel burdens on residents, particularly those who were captive transit users before (Palm et al., 2021).

Although the pandemic has affected every resident of megacities, the impact has not been evenly distributed across geographic areas and population groups. First, the neighborhood environment may moderate the impact of the pandemic. As a result of the travel restrictions and bans, and perceived risk of infection, many travel activities have been localized. This has implied a greater impact of the neighborhood environment in supporting people's daily life. For example, a walkable neighborhood that has grocery stores and parks nearby may well meet the daily needs of its residents during a lockdown. This reduces the impact of the pandemic on their life and mental wellbeing. On the other hand, residents living in a sprawling neighborhood with limited access to amenities, on the other hand, may have found it difficult to shop and exercise, potentially increasing their stress and anxiety. Although many previous studies (Gidlow et al., 2010; Leslie and Cerin, 2008; Qiu et al., 2019; Wood et al., 2017) have examined the link between various

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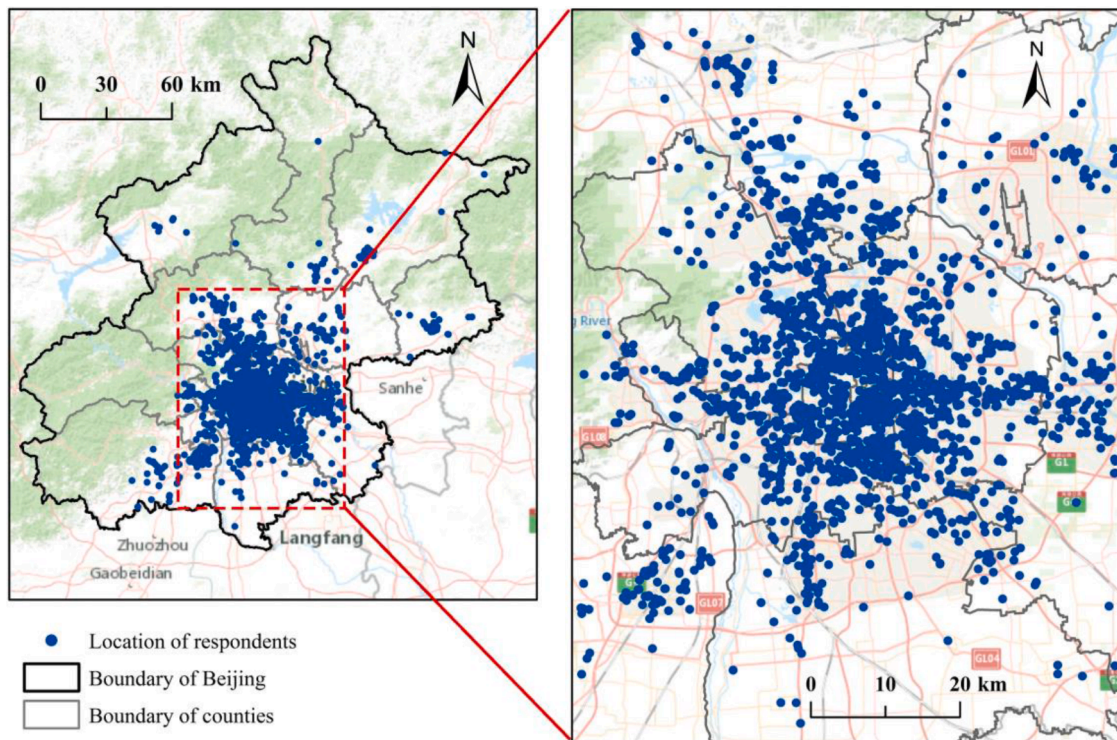


Fig. 1. Spatial distribution of the sampling households.

Table 1
Factor loadings for mental health status.

	Mental health status
I was bothered by things that usually don't bother me	0.7530
I had trouble keeping my mind on what I was doing	0.6369
I felt depressed	0.8333
I felt that everything I did was an effort	0.7858
I felt fearful	0.7645
My sleep was restless	0.5793
I felt lonely	0.7432
I could not get going	0.6917

neighborhood environment features (e.g., open space, building density, walkability, community aesthetics, and mixed land use) and mental health outcomes, few have investigated how the neighborhood environment might help to moderate the mental health impact in a natural disaster context. Second, given the disparities in socio-economic conditions and neighborhood environment, the impacts of the pandemic have not been homogeneous among different population groups (Yang and Xiang, 2021). Vulnerable groups such as low-income people, minorities, and urban migrants are more likely to live in neighborhoods with poor social and built environments. As a result, they may experience more mental health risks during emergency events such as the COVID-19 pandemic (Aragona et al., 2020; Hubbard et al., 2021).

Through collecting survey data ($n = 2,741$) in the Beijing metropolitan area during the pandemic, we investigated the relationship between the neighborhood environment and mental health impact. In particular, we explored how this relationship varies between lower and higher income groups. This study has two scientific contributions. First, the findings of this study provide new insights into the relationship between the neighborhood environment and mental health. Instead of focusing on the mental health status during the COVID-19 pandemic, we examined the association between neighborhood environment and the changes of the mental health (i.e., psychological resilience). This research design contributes to better understand the mechanisms of the neighborhood environment in supporting mental wellbeing in an

emergency event. Second, our study reveals heterogeneity in the effects of neighborhood environment on mental health impact across different population groups. Exploring the disparity in mental health impact among different demographic groups and its association with the neighborhood environment helps to better understand the synergistic effects of socio-economic and environmental disadvantages on mental health during the pandemic. Moreover, the current COVID-19 pandemic has caused a serious health crisis in cities worldwide and calls for a significant effort to design resilient cities and communities (Buyukozkan et al., 2022). Therefore, our study also has practical significance, and informs policies on resilient communities and environmental justice.

2. Conceptual framework

Planning for resilient cities and communities are important for future cities to better resist and bounce back from the negative impacts of unanticipated calamities (Meerow et al., 2016). The current COVID-19 pandemic has caused a serious health crisis in cities worldwide and called for a significant effort to design resilient cities and communities (Buyukozkan et al., 2022). Many studies have pointed out the capacity of cities to prevent and control the pandemic as an aspect of urban resilience, and highlighted the important role of urban planning and urban governance in enhancing the urban resilience against COVID-19 pandemic (Allam and Jones, 2020; Chen et al., 2021a; Gaisie et al., 2022; Megahed and Ghoneim, 2020). In addition to the harm of the coronavirus itself, the increasing mental illness due to the pandemic has also become an important health issue (Menculini et al., 2021). The instability and uncertainty associated with the COVID-19 pandemic, lockdown policy, and other economic and social risks have created instability and uncertainty. This has elevated levels of despair, anxiety, and stress, resulting in a deterioration of mental health (Moreno et al., 2020). During the first two months of the pandemic, nearly 35% of Chinese respondents reported that they experienced psychological distress (Qiu et al., 2020). Further, several studies have found that vulnerable groups, such as women, the unemployed, older adults, and

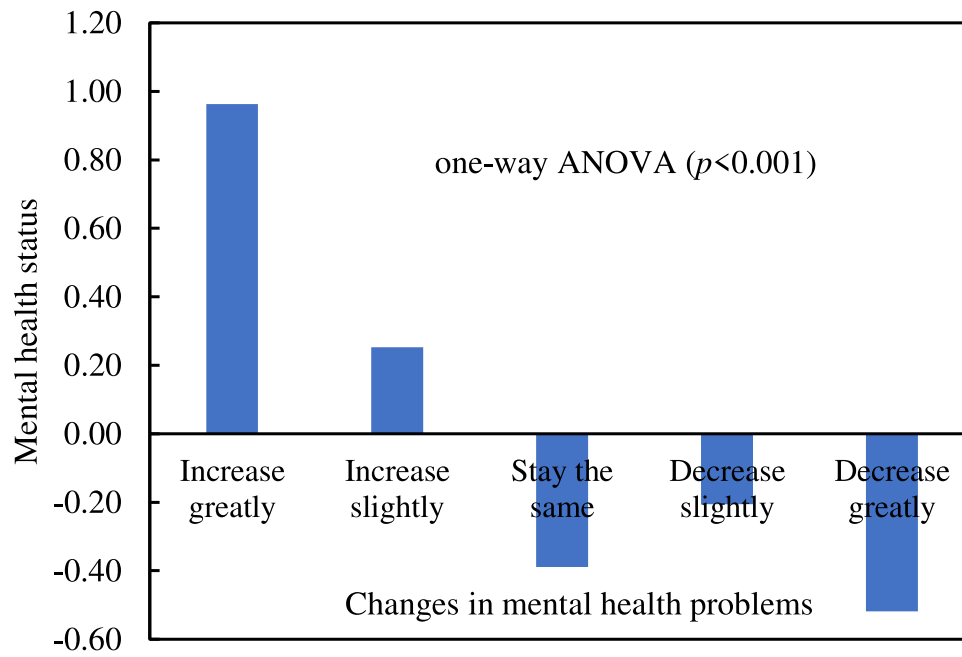


Fig. 2. Relationship between mental health status and mental health impact.

Table 2
Factor loadings for 'walkability'.

	Walkability within 500m	Walkability within 800m
Subway station density	0.5628	0.7343
Bus stop density	0.6105	0.6912
Road density	0.8444	0.8874
Population density	0.8504	0.8871
POI density	0.7774	0.8675
Building density	0.8491	0.8794

migrant workers were at a higher risk of suffering mental illnesses (Fiorillo et al., 2020; Qiu et al., 2020).

Neighborhood environment is an important element of resilient cities (Kontokosta and Malik, 2018), and plays a significant role in reducing mental health risks (Kontokosta and Malik, 2018; Yang and Xiang, 2021). In general, neighborhood environment usually consists of built environment (e.g., building density, land use, and green open space) and social environment (e.g., discrimination, crime, and neighborhood support) (Gidlow et al., 2010). The impact of the built environment on mental health is usually achieved through two main pathways. First, the built environment can increase or decrease people's exposure to mental health-related environmental elements (e.g., noise and air pollutants), which directly influence people's moods and emotions. These have been shown to have a direct impact on mental health (Empson et al., 2020). Close proximity to traffic, for example, may expose people to increased noise and air pollution, thereby harming their mental health (Klompaker et al., 2019; Ma et al., 2018a). Furthermore, the effect of the objective built environment on residents is also achieved through subjective environmental perception (Ma et al., 2014). The perception of the built environment effects neighborhood satisfaction and sense of community, which in turn impacts mental health (Leslie and Cerin, 2008; Tang et al., 2021). Second, the built environment can also shape and change people's health-related behaviors and social communication (Empson et al., 2020; Roux, 2016). Good urban design encourages people to engage in physical activity, which improves their physical and mental health. Residents who live in a walkable neighborhood are more inclined to walk to nearby destinations and engage in social activities. This increase in physical activity and social interactions will lead to better (physical and mental) health and

well-being (Ma et al., 2018b; Owen et al., 2007; Wang and Yang, 2019).

Among the built environment variables, green space is widely regarded as an important element that promotes health and well-being (Douglas et al., 2017; Xie et al., 2018). Green spaces can directly relieve people's psychological stress, and also alleviate the negative impact of poor urban environment on mental health by reducing noise and air pollution (Wang et al., 2021). Furthermore, green spaces can also affect health and well-being through indirect pathways. Encouraging physical activity is considered to be one of these causal paths (Qin et al., 2021). Physical activity can alleviate the symptoms of depression and anxiety, causing positive effects on mental health and subjective well-being (Stathopoulou et al., 2006). Some studies have shown that proximity to green spaces and parks promotes levels of physical activity (Fan et al., 2011; Zhang et al., 2020). In terms of different types of green spaces, parks that serve as physical activity spaces have a greater positive effect on residents' mental health than parks that merely serve as recreational and natural spaces (Wood et al., 2017). Moreover, green spaces also facilitate social activities and interactions (Brown et al., 2018; Kazmierczak, 2013), and improve social cohesion and sense of community (Jim and Shan, 2013; Liu et al., 2019).

As people's daily activities have been confined within their neighborhood during the COVID-19 pandemic, the impact of neighborhood environment on mental health has been amplified (Teo et al., 2021). As a result, the neighborhood environment can be viewed as a moderating element that can either reduce or enhance the detrimental effects of the pandemic on mental health. A quiet and well-maintained neighborhood environment can help people cope with the negative psychological impact of the COVID-19 pandemic (Chen et al., 2021b). Furthermore, urban green spaces not only provide citizens with spaces to exercise and relax, but also help them catch their breath and get away from the virus (Ugolini et al., 2020). Several studies have found that there was an increase in the frequency of visits to green open spaces during the COVID-19 pandemic (Beckmann-Wubbelt et al., 2021; Ugolini et al., 2020). In addition, a highly walkable neighborhood may better meet the life needs of its residents during lockdown by reducing the negative impact of the pandemic. However, a highly walkable neighborhood usually has a relatively higher population density, and this may well have increased the perceived risk of COVID-19 infection (Gaisie et al., 2022).

In addition to the built environment, the social environment is also

Table 3
Descriptive statistics of independent variables.

Independent variables	Mean/Percentage			T statistics or χ^2
	Total	Lower income	Higher income	
Walkability score within 500 m buffer	0.091	-0.024	0.221	6.79***
Walkability score within 800 m buffer	0.091	-0.014	0.210	6.19***
Distance to the nearest park (km)	1.613	1.689	1.528	-2.94***
Received neighborhood help during COVID-19 (1 = Yes)	48.12%	48.15%	48.09%	0.00
Satisfaction of community services	4.261	4.262	4.260	-0.08
Age	36.501	37.755	35.072	-5.48***
Have Beijing Hukou	59.47%	51.10%	69.01%	90.83***
Female	50.31%	50.82%	49.73%	0.33
Marital status				17.66***
Never married	43.52%	43.49%	43.56%	
Married	51.62%	50.07%	53.40%	
Divorced or widowed	4.85%	6.44%	3.04%	
Household income (thousand yuan/year)				
Below 30	18.13%			
30-50	13.68%			
50-100	21.45%			
100-200	26.60%			
200-500	16.67%			
500-1000	2.59%			
1000 and above	0.88%			
Extroverted in personality	6.723	6.534	6.939	5.51***
Home ownership				147.75***
Owned	49.11%	39.18%	60.42%	
Joint ownership	4.60%	4.79%	4.37%	
Rented	31.96%	36.30%	27.01%	
Government provided free of charge	1.42%	1.85%	0.94%	
Danwei ² provided free of charge	4.38%	5.75%	2.81%	
Stay with relatives/friends	2.77%	3.63%	1.80%	
Dormitory	3.79%	5.68%	1.64%	
Other	1.97%	2.81%	1.01%	
HH size	3.085	3.032	3.145	2.31**
Neighborhood currently been locked down (1 = Yes)	53.74%	56.71%	50.35%	11.11***
Have been quarantined (1 = Yes)	34.55%	36.58%	32.24%	5.67**
Confirmed cases in neighborhood (1 = Yes)	5.14%	3.84%	6.64%	10.96***
Changes in levels of leisure and physical activity	3.464	3.474	3.453	0.385
Observations	2,741	1,460	1,281	

Note: t-test and chi-square test are used to test the disparities in independent variables between lower and higher income groups. The result is shown in the last column. * $p < 0.1$

** $p < 0.05$

*** $p < 0.01$

² Danwei is a legacy of the Planned Economy in China. The main defining feature of a Danwei is its multi-functionality as a place of employment, residence, education and commerce.

believed to have an effect on mental health (Jia et al., 2021). Insecurity, violence, neighborhood distrust, and social discrimination (including geographic and racial discrimination) can reduce people's social involvement and social support. This compromises their subjective well-being and mental health (Ventriglio et al., 2021). In contrast, residents in communities with higher levels of social engagement, cohesion, and trust not only have higher subjective well-being, but also receive more social support to offset or mitigate psychological distress. Thoits (2011) argued that social support has a positive effect on mental health by providing both active coping assistance and emotional support. Active coping assistance emphasizes the use of information and

tools provided by supporters (e.g. approaches to solving problems or venting feelings, etc.) to directly reduce the psychological and physical outcomes of the stressor (Thoits, 1986). Emotional support (e.g., care, valuing, and understanding) often indirectly affects emotional and psychological status through some psychosocial mechanisms (e.g., enhancing the sense of belonging and self-esteem) (Thoits, 2011). When faced with a disaster, people who live in communities with a greater sense of well-being and cohesion are able to receive better social support from their neighbors, resulting in stronger psychological resilience to resist the negative effects of disasters (Song and Li, 2019).

Furthermore, although many studies have focused on the correlation between socio-demographic variables and mental health, sometimes this relationship might be manifested through the built and social environment. People's socio-demographic characteristics (e.g., income, ethnicity) are closely associated with the built and social environment of their living communities, and this association may lead to inequalities in health (Roux, 2016). During a public emergency, inequalities in the built and social environment may amplify the impact of socio-demographic characteristics on mental health (Akbari et al., 2021). During the COVID-19 pandemic, minorities and vulnerable groups have faced more mental health issues than the general population (Aragona et al., 2020). This is partially due to their socio-economic disadvantages, but also because of their lower levels of accessibility to facilities and services (e.g., health care services) (Menculini et al., 2021).

The COVID-19 pandemic has motivated urban planners and authorities rethink how to design resilient cities and communities that promote psychological resilience. The limited studies on the correlation between neighborhood environment and mental health during the COVID-19 pandemic have only focused on people's mental health status, rather than the changes of the mental health, associated with the neighborhood environment. In fact, in psychology-related studies, post-disaster symptoms of psychological disorders are characterized by a variety of symptom trajectories, including resistance, resilience, recovery, and chronic dysfunction (Norris et al., 2009). In this paper, we examine whether residents could resist the negative effects of the COVID-19 pandemic on their mental health and preserve a healthy psychological status. This capacity to continue psychologically functioning during a traumatic event, and cope and adapt normally with the event is known as psychological resilience (Bonanno, 2005; Goldmann and Galea, 2014). Based on this concept, we investigate which elements of a neighborhood environment helped residents avoid worsening mental health and improve their psychological resilience during the COVID-19 pandemic. We highlight the importance of the neighborhood environment in the COVID-19 pandemic from the perspective of improving psychological resilience. Our study presents a new research perspective and provides implications for planning resilient communities.

3. Methodology

3.1. Survey data

Our primary method of data collection was a self-administered survey, which was distributed in Beijing, China, between July 10th and 28th, 2020. The survey period was immediately following the second wave of the pandemic's breakout in June. Except for a few at-risk communities that were under full lockdown throughout the survey period, the majority of Beijing areas allowed residents to travel, however residents were urged to minimize unnecessary trips. Due to the travel restrictions, we collaborated with a panel company to recruit participants and conduct an online survey. To guarantee that the sample was representative in terms of gender, age, and geographic distribution, questionnaires were distributed using a stratified sampling procedure. We finally obtained a sample of 3028 individuals who had lived in Beijing for at least six months. Given the availability of built environment data, we only investigated the psychological resilience of residents

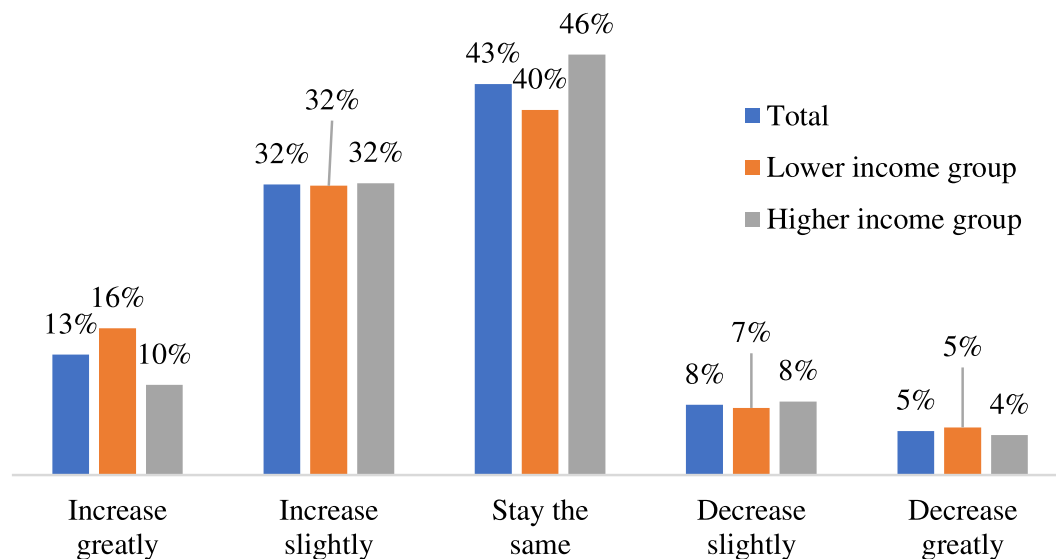


Fig. 3. Changes in frequency of experiencing mental health problems.

living in urban communities. After eliminating samples in rural communities and with missing information, the final sample size for the analysis is 2741. The spatial distribution of the sample is shown in Fig. 1. The dataset includes residents' socio-demographic characteristics, housing conditions, perceived neighborhood environment, self-reported health status, and information related to the COVID-19 pandemic.

Furthermore, we divided the respondents into lower- and the higher-income groups, to explore the disparity of the pandemic impact between different socioeconomic groups. According to the "Beijing Statistical Yearbook (2021)", the average annual income of urban residents was 44,620 yuan in 2020. Since the average household size in Beijing was 2.31 members according to the 7th Census data (2020), the average yearly household income in urban area is about 103,000 yuan. Residents with an annual household income of less than 100,000 yuan are classified into the lower income group, while those with an annual household income of more than 100,000 yuan are classified into the higher income group. The respondents in the lower income group account for 53.2% of the total sample size.

3.2. Outcome variables

Two mental health variables were extracted from the survey: the mental health status during the COVID-19 pandemic and the mental health impact of the pandemic. First, participants were asked to report the frequency of various negative emotions they had experienced in the past week. These negative emotions include eight aspects associated with depression (see Table 1). These statements are adapted from the Center for Epidemiologic Studies Depression Scale (CESD Scale) (Radloff, 1977; van Dam and Earleywine, 2011). The answer of each question was coded using a 4-point Likert scale: '1-little or never (less than 1 day a week)', '2-sometimes (1-2 days a week)', '3-often (3-4 days a week)', and '4-most of the time (5-7 days a week)'. Based on the eight questions related to negative emotions, we extracted a principal component by applying principal component analysis (Table 1) and calculated a composite score of mental health (mental health status). A higher score indicates a more severe mental health problem during the COVID-19 pandemic.

Second, we measured the mental health impact of the pandemic as an outcome variable, and this study focuses on this outcome variable. This variable was measured by asking the residents to report how their recent experience of the following mental health conditions (including depression, restlessness, loneliness, fear, etc.) changed, compared to normal days in 2019. This variable was coded using a 5-point Likert

scale: '1-increase greatly', '2-increase slightly', '3-stay the same', '4-decrease slightly', and '5-decrease greatly'. As we focus on examining how neighborhood environments might help to mitigate the negative mental health impact of the pandemic, we merged the categories of 'decrease greatly', 'decrease slightly', and 'stay the same' into the 'no increase' category. We created an outcome variable that reflects the level of the increase in mental health problems (0-no increase vs. 1-increase slightly vs. 2-increase greatly). Further, we explored the relationship between mental health status and mental health impact (Fig. 2). Participants who reported a significant increase in negative emotions faced higher risks of mental health issues during the pandemic. Conversely, participants who reported their negative emotions stayed the same or decreased faced lower risks of mental health issues.

3.3. Explanatory and control variables

The neighborhood environment is the core variable and includes the built environment and the social environment. Based on a GIS approach and dataset, six neighborhood-level built environment variables were calculated, including subway station density, bus stop density, road density, population density, POI (point of interest) density, and building density. A 500-meter and 800-meter buffer was used to calculate all neighborhood-level built environments. These buffers are commonly used as distance thresholds for studying the daily activities of residents (Liu et al., 2021; Wang et al., 2021). To reduce the dimensions of the built environment variables, we applied a principal component analysis. One principal factor was extracted and named as 'walkability'. The factor loadings for 'walkability' are shown in Table 2.

Further, park accessibility was treated as an independent variable as it may influence mental health differently compared to walkability. This variable was measured by calculating the Euclidean distance from the respondents' home address to the nearest park. In terms of the social environment, three indicators were incorporated: neighborhood relationships, community support and discrimination. For neighborhood relationships, we asked respondents to report whether they had received help from their neighbors during the pandemic. For community support, we asked respondents about their satisfaction with the services offered by the neighborhood. A five-point Likert scale was used to measure the level of the services from 'very unsatisfactory' (1) to 'very satisfactory' (5). For perceived discrimination, we asked the respondents to report whether they felt discriminated against during the pandemic because of their status as 'outsiders'. This variable was also coded using a five-point Likert scale from 'not at all' (1) to 'strongly' (5). Moreover, respondents

Table 4
Model results.

	Model 1		Model 2	
	Coef.	SE	Coef.	SE
Neighborhood environment				
Walkability score within 500m buffer	0.055	0.049		
Walkability score within 800m buffer			0.063	0.048
Distance to the nearest park	0.042**	0.022	0.046**	0.019
Neighborhood help	0.080	0.067	0.079	0.067
Satisfaction of community services	-0.301***	0.062	-0.302***	0.062
Regional discrimination	0.231***	0.047	0.231***	0.047
Personal and household factors				
Age	-0.009**	0.003	-0.009**	0.003
Beijing hukou	0.280***	0.072	0.278***	0.072
Female	0.005	0.119	0.005	0.119
Marital status				
Never married	Ref.		Ref.	
Married	-0.155	0.121	-0.155	0.120
Divorced or widowed	0.337**	0.164	0.339**	0.166
HH income	-0.054*	0.032	-0.054*	0.032
Extroverted	-0.097***	0.025	-0.097***	0.025
Housing conditions				
Home ownership				
Owned	Ref.		Ref.	
Joint ownership	0.396***	0.103	0.394***	0.102
Rented	0.441***	0.098	0.442***	0.098
Government provided free of charge	-0.473*	0.261	-0.470*	0.261
Danwei provided free of charge	0.391**	0.152	0.393**	0.153
Stay with relatives/friends	0.156	0.153	0.156	0.152
Dormitory	0.430**	0.213	0.430**	0.213
Other	0.177	0.299	0.178	0.300
HH size	0.081**	0.032	0.081**	0.032
Factors associated with COVID-19				
Neighborhood currently been locked down (1 = Yes)	0.027	0.068	0.025	0.067
Have been quarantined (1 = Yes)	0.518***	0.087	0.516***	0.086
Confirmed cases in neighborhood (1 = Yes)	0.379***	0.118	0.378***	0.118
Constant	0.996***	0.278	0.997***	0.279
Gamma 2: "Slightly worse" to "Much worse"				
Neighborhood help	-0.374***	0.126	-0.374***	0.126
Satisfaction of community services	0.163**	0.069	0.164**	0.069
Female	-0.177**	0.089	-0.177**	0.089
HH income	-0.104***	0.019	-0.104***	0.019
Constant	-0.927**	0.392	-0.928**	0.278
Observations	2,741		2,741	
LR Chi ² (degrees of freedom)	5319.26(13)		1471.13(13)	
Model significance	0.000		0.000	
Pseudo R ²	0.054		0.054	

Note: Dependent variable = levels of the increase in mental health problems (0= no increase vs. 1=increase slightly vs. 2=increase greatly).

* $p < 0.1$
 ** $p < 0.05$
 *** $p < 0.01$

Table 5
Estimation results of independent variables that do not pass the parallel line assumption.

Model Increment	Model 1		Model 2	
	0→1	1→2	0→1	1→2
Neighborhood help	Coef. (SE) 0.080 (0.067)	Coef. (SE) -0.293*** (0.102)	Coef. (SE) 0.079 (0.067)	Coef. (SE) -0.295*** (0.102)
Satisfaction of community services	-0.301*** (0.062)	-0.138** (0.069)	-0.302*** (0.062)	-0.138** (0.069)
Female	0.005 (0.119)	-0.172* (0.092)	0.005 (0.119)	-0.172* (0.093)
HH income	-0.054* (0.032)	-0.158*** (0.025)	-0.054* (0.032)	-0.158*** (0.037)

Note: * $p < 0.1$
 ** $p < 0.05$
 *** $p < 0.01$

were also asked to report the changes in levels of leisure and physical activity during the pandemic compared with normal circumstances in 2019. A five-point Likert scale was used to code this variable, ranging from 'increase greatly' (1) to 'decrease greatly' (5).

The control variables consist of three other groups of factors: individual and household factors, housing conditions, and other factors associated with the pandemic. Individual and household factors include age, gender, marital status, household income, and personality characteristic. We also asked respondents whether they have a Beijing 'Hukou'¹, since 'Hukou' not only influences identification but also leads to inequity in the distribution of public resources and services among urban residents (Afridi et al., 2015). In addition, respondents were asked to rate how extroverted they consider themselves. This variable is used to describe the personality characteristic and its value ranges from 0 to 10, with 0 indicating introverted and 10 indicating extroverted. Home ownership and household size are two factors that reflect housing conditions. Several studies have suggested that the impact of housing condition on mental health has been significant during the pandemic (Amerio et al., 2020; Ghimire et al., 2021). Finally, we asked the respondents to report whether their neighborhoods were currently under lockdown, whether they have ever been quarantined, and whether there were confirmed cases in their neighborhood.

3.4. Statistical model

Ordered logistic regression modeling is commonly used when the dependent variable is an ordered multiple classification. However, conventional ordered logistic regression modeling requires the data to meet a proportional odds assumption, which could often be violated in real practice (Li and Fan, 2020). Consequently, we choose the partial proportional odds model to assess the effect of neighborhood environment on mental health during the pandemic. The partial proportional odds model allows modeling of the effects of the covariates that meet the proportional odds assumption and the covariates that do not meet the assumption separately (Williams, 2016). The regression models were estimated using Stata 15.0.

4. Results and discussion

4.1. Descriptive analysis

The descriptive statistics for the independent variables are shown in Table 3. We first investigate the differences in socioeconomic characteristics and neighborhood environment between lower and higher income groups. Household income is associated with many factors, including age, hukou, housing conditions, extroverted personality, and neighborhood environment. In terms of socioeconomic characteristics, the percentage of lower income people with Beijing hukou is much less than that of higher income people. Moreover, lower income people also have worse housing conditions, with a smaller percentage of people reporting they have their own housing. In terms of neighborhood environment, lower income people live in neighborhoods with a lower walkability score and lesser access to urban parks, as well as higher levels of discrimination. In terms of neighborhood help and satisfactory community services, there are no differences between lower and higher income groups. These disparities suggest that household income is a good predictor for determining vulnerability.

The different mental health impacts of the pandemic by income group are shown in Fig. 3. About 45% of the respondents reported their mental health become worse in the pandemic, 43% reported their

¹ Hukou is an official document issued by the Chinese government, certifying that the holder is a legal resident of a particular area. Only Hukou registered citizens in a city have access to specific local services and benefits, including as certain jobs, the housing fund, public housing, and schools.

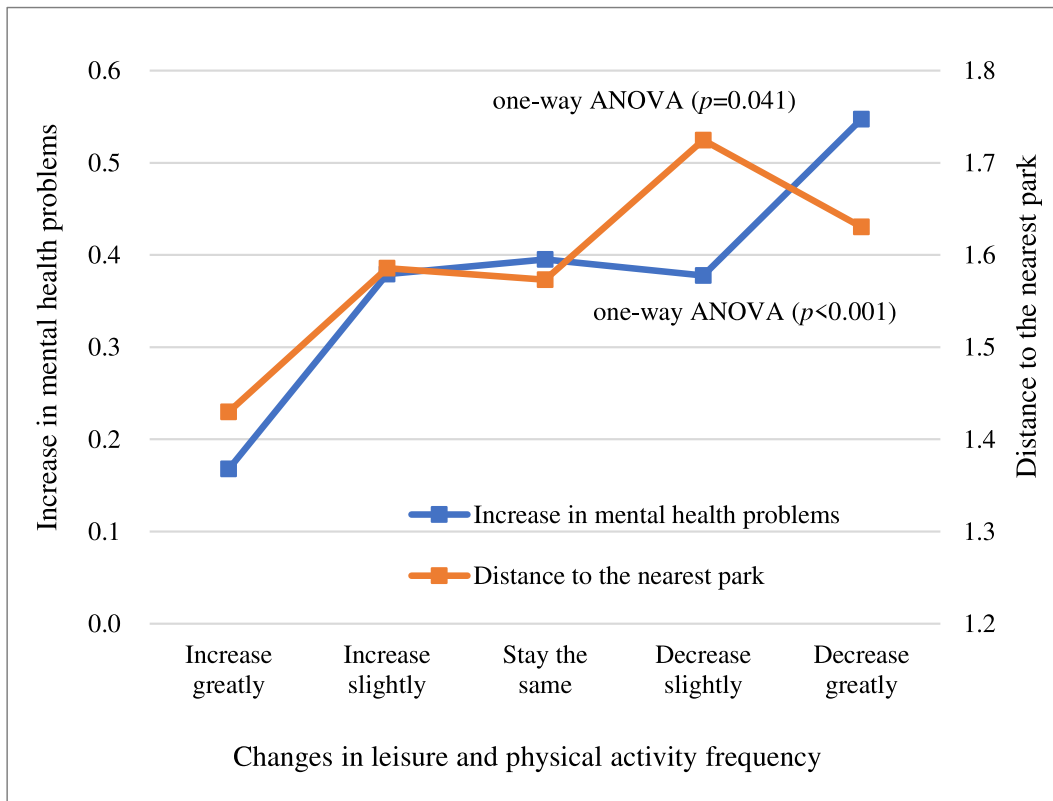


Fig. 4. Relationship between park accessibility, change in leisure and physical activity frequency, and mental health impact.

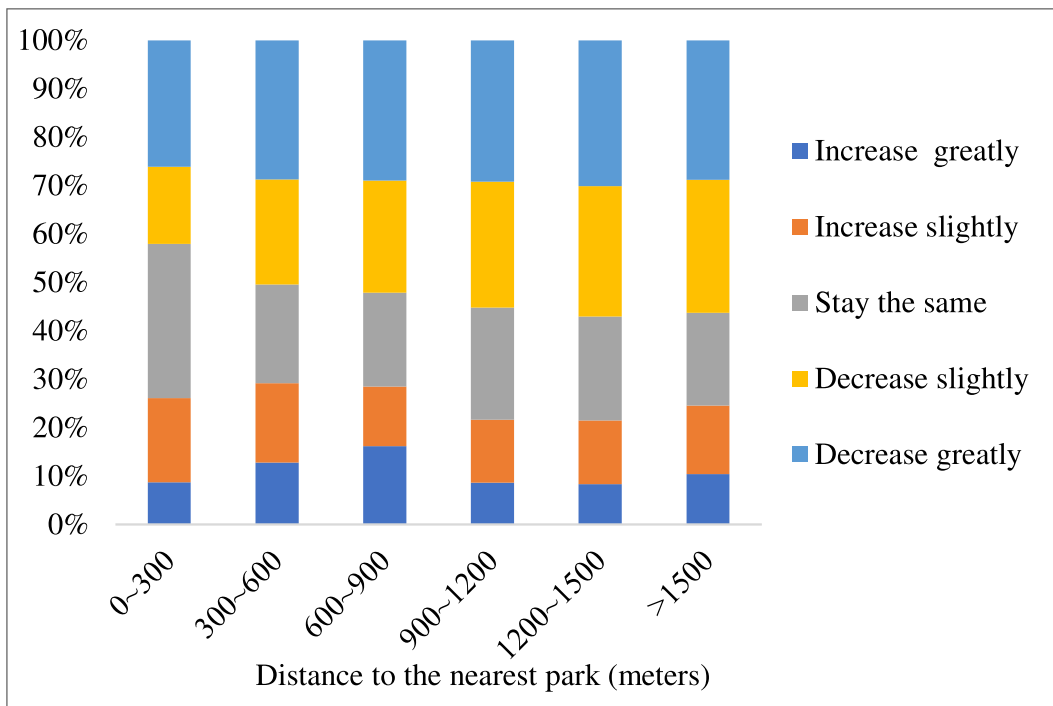


Fig. 5. Relationship between changes in activity frequency and proximity to park.

mental health stayed the same, and around 12% reported their mental health improved. Furthermore, the proportion of the lower-income group experiencing a significant increase in negative emotions during the pandemic was greater than that of higher-income group (16 vs. 10%), while the proportion of lower-income group that did not change

in mental health during the pandemic was lower than that of higher-income group (40 vs. 46%). This suggests that lower-income residents are more likely to suffer negative mental health impacts during an emergency situation such as the COVID-19 pandemic.

Table 6
Model results by different income groups.

	Lower income group		Higher income group	
	Model 1	Model 2	Model 1	Model 2
Neighborhood environment				
Walkability score within 500m buffer	0.081		0.004	
Walkability score within 800m buffer		0.125		-0.031
Distance to the nearest park	0.073*	0.089**	-0.017	-0.030
Neighborhood help	0.067	0.062	0.043	0.046
Satisfaction of community services	-0.264***	-0.265***	-0.302***	-0.300***
Regional discrimination	0.233***	0.231***	0.209***	0.211***
Personal and household factors				
Age	-0.013**	-0.014***	-0.001	-0.000
Beijing hukou	0.331*	0.325*	0.246	0.253
Female	0.054	0.059	-0.171	-0.174
Marital status				
Never married	Ref.	Ref.	Ref.	Ref.
Married	-0.068	-0.064	-0.292*	-0.293*
Divorced or widowed	0.378**	0.389**	0.223	0.223
HH income	-0.023	-0.024	-0.117	-0.115
Extroverted	-0.100***	-0.099***	-0.095***	-0.095***
Housing conditions				
Home ownership				
Owned	Ref.	Ref.	Ref.	Ref.
Joint ownership	0.438***	0.428***	0.403**	0.404**
Rented	0.688***	0.695***	0.139	0.140
Government provided free of charge	-0.480	-0.480	-0.248	-0.245
Danwei provided free of charge	0.548**	0.548**	0.243	0.248
Stay with relatives/friends	0.063	0.072	0.463	0.469
Dormitory	0.373	0.372	0.975***	0.987***
Other	0.262	0.266	0.087	0.068
HH size	0.072	0.072	0.094*	0.095*
Factors associated with COVID-19				
Neighborhood currently been locked down (1=Yes)	-0.020	-0.021	0.088	0.091
Have been quarantined (1=Yes)	0.572***	0.570***	0.449***	0.453***
Confirmed cases in neighborhood (1=Yes)	0.357	0.353	0.350***	0.347***
Constant	0.765**	0.759**	1.341**	1.330**
Gamma 2: "Slightly worse" to "Much worse"				
Neighborhood help	-0.455***	-0.455***		
Satisfaction of community services			0.290***	0.290***
Age			-0.016***	-0.016***
Marital status				
Married			0.255**	0.255**
Divorced or widowed			0.858**	0.858**
Constant	-0.754**	-0.762**	-1.451***	-1.462***
Observations	1,460	1,460	1,281	1,281
LR Chi ² (degrees of freedom)	1795.33 (13)	1578.20 (13)	1703.70 (13)	1655.23 (13)
Model significance	0.000	0.000	0.000	0.000
Pseudo R ²	0.067	0.068	0.040	0.040

Note: * $p < 0.1$
** $p < 0.05$
*** $p < 0.01$

4.2. Role of the neighborhood environment in the mental health impact of the COVID-19 pandemic

We applied a partial proportional odds model to examine the association between the neighborhood environment and mental health impact of the pandemic. The independent variables that do not pass the parallel line assumption are identified by automatic constraints (autofit) of the model. Table 4 shows the estimation results of the partial proportional odds model, and Table 5 shows the coefficients of the

independent variables that do not satisfy the parallel line assumption. In terms of the built environment, there is no significant association between walkability score and mental health impact of the pandemic using either the 500-m or 800-m buffer as the unit of measurement. Although many previous studies have suggested a positive association between walkability and mental health or life satisfaction, we did not find that walkability is associated with better mental health outcomes. This is probably because Beijing, overall, has a relatively walkable environment with a high-density built environment and mixed land use that provides a high level of accessibility to services and amenities (Long and Liu, 2013; Zhang and Zhao, 2017). The distance to an urban park, however, has a significant and positive association with the mental health impact of the pandemic. Residents who live near urban parks are more resilient to the negative psychological impact of the pandemic.

In terms of social environment, neighborhood help, satisfaction of community services, and perceived discrimination are all associated with the level of mental health impact. First, neighborhood help is negatively associated with increased mental health problems. Second, satisfaction with community services is associated with a reduced risk and severity of mental health problems. These findings imply that community-level initiatives and services are important to improve the psychological resilience of its residents. Moreover, the perceived discrimination is associated with deteriorating mental health.

As park accessibility is the only built environment variable significantly associated with mental health impact, we further explored the possible mechanism of this relationship. Previous studies have shown that green open space improves people’s mental health by increasing their physical activities (Wood et al., 2017). In our study, the level of leisure and physical activity was considered as a potential mediator. First, we investigated whether change in leisure and physical activity frequency is associated with mental health impact and park accessibility (Fig. 4). Overall, those who lived close to a park were more likely to report a significant increase in levels of leisure and physical activity and less likely to experience worsening mental health in the pandemic. Conversely, those living further away from a park were more likely to report a significant decrease in levels of leisure and physical activity and more likely to report an increase in mental health problems. We further plotted the relationship between distance to park and changes in leisure and physical activity frequency in Fig. 5. Overall, the share of the respondents whose levels of leisure and physical activities increased or stayed the same, decreased over the distance from a park. This implies that park accessibility has been an important influencing factor on people’s participation in leisure and physical activities during the pandemic, and thereby has impacted their mental health.

For other variables, we find that age and Beijing Hukou affect the mental health impact of the pandemic. Younger adults were more likely to be psychologically impacted than older adults. Surprisingly, those who have Beijing Hukou were more likely to suffer negative mental health impacts than urban migrants, who may have better psychological resilience than the local residents. As expected, those with higher household incomes and extroverted personalities reported a less negative mental impact from the pandemic, while those who were widowed or divorced reported an increased level of mental health problems. Compared with men, women have better resilience in mental health, though this gender difference is marginally significant (Table 5). In terms of home ownership, people who rent or share with others are more likely to suffer worsening mental health in the pandemic.

4.3. Variations between lower and higher income group

We further explored whether the association between the neighborhood environment and mental health impact of the pandemic varies between lower and higher income groups. We estimated separate models for the lower and higher income group and the regression model results are reported in Table 6. Mostly, the neighborhood environment variables show similar correlations with the mental health impact

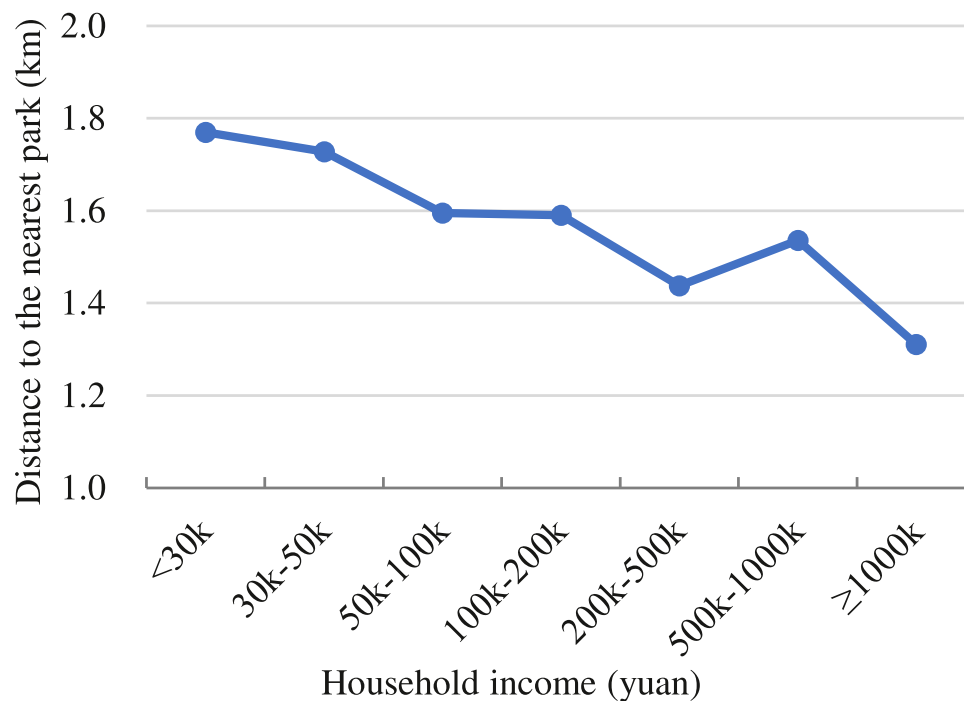


Fig. 6. Relationship between household income and distance to the nearest park.

between the lower and higher income group. For example, walkability is not significantly associated with mental health impact in either the lower or higher income group, though higher income neighborhoods have higher walkability scores. Moreover, satisfaction of community services and perceived discrimination have similar associations with the mental health impact in both lower and higher income groups, although respondents from the lower income group reported more perceived discrimination.

The correlation between park accessibility and the mental health impact of the pandemic, however, is different between the lower and higher income group. The distance to a park is significantly correlated with the mental health impact in the lower income group, but not in the higher income group. This is probably because a park near home is one of the limited options for lower income residents to engage in leisure and physical activities, while the higher-income residents have more available options (e.g., gyms or sports centers) to relax and participate in physical activity. This finding may highlight the importance of park accessibility in supporting mental health for the lower income population, who are more likely to suffer negative psychological impact in a pandemic. Previous research has suggested the heterogeneities in the impact of green open space on mental health across income groups, and found greater benefit for lower income people (Brown et al., 2018). A study in Beijing indicated that park accessibility within 300 meters has a significant effect on lower income people's self-rated health, while the effect on higher income people's self-rated health is not significant (Wu and Kim, 2021).

Fig. 6 shows the relationship between household income and distance to the nearest park. It suggests a disparity of park accessibility between different income groups. The lower-income residents have a relatively lower level of park accessibility, though park accessibility has a stronger association with the mental health impact in the lower-income group than in the higher-income group. This result implies that planning policies that focus on improving park accessibility in lower-income neighborhoods in Beijing may help to improve the well-being and resilience of these neighborhoods.

5. Conclusion and policy implication

The COVID-19 pandemic has triggered a significant increase in prevalence of anxiety and depression worldwide. In this study, we examined the role of the neighborhood environment in moderating the mental health impact of the pandemic. We also investigated whether this impact varies between different income groups, and how the neighborhood environment may contribute to this difference. We examined these questions through a survey analysis of local residents of Beijing during the pandemic. This study contributes to the growing literature linking neighborhood environment and mental health by focusing on the changes in mental health resulting from a public health crisis, under which people's daily activities are largely restricted to their neighborhoods. It also provides new insights into planning for healthy and resilient neighborhoods.

Overall, we found that a large share of the respondents reported their mental health has become worse during the pandemic. Both neighborhood built and social environments contributed to this impact. This finding highlights the importance of neighborhood environments in supporting people's psychological resilience in a public health crisis. In particular, we found that living close to a park is associated with better mental health resilience (i.e., not getting worse in mental health). Our results further demonstrate that park accessibility may abate the mental health impact of the pandemic by promoting participation in leisure and physical activities. In addition to the built environment, we found that neighborhood social cohesion and good community services have helped to support people's mental health. This result highlights the importance of the neighborhood social environment in response to a public emergency.

Further, we found the mental health impact of the pandemic is not equally imposed on the population. The lower-income residents in Beijing suffered more mental health problems than the higher-income residents. This different health impact between income groups can be attributed to institutional barriers (e.g., lack of accessibility), as well as COVID-19 induced economic (e.g., unemployment) and social issues (e.g., discrimination against low-income people). We particularly examined the role of park accessibility on the different mental health impact of the pandemic. We found the positive effect of park accessibility on

mental health is stronger in the lower-income group than in the higher-income group. However, the lower-income group has lower levels of park accessibility compared to the higher-income group in Beijing. This finding suggests that disparity of neighborhood environment contributes to health inequalities between income groups.

Our study also provides some implications for urban planning and public policy. First, community parks should be considered an important element of a resilient neighborhood and city. Parks not only provide attractive spaces for residents to engage in social and physical activity, and interact with nature, but can also serve as evacuation sites in other types of emergency events or disasters (such as an earthquake). Further, parks can also serve as a gathering place during disasters where local residents can build social coalition and support (Roe and McCay, 2021). The role of parks in planning for neighborhood resilience has also been discussed in the context of various types of disasters, including natural (e.g., extreme heat, earthquakes, cyclones) and man-made disasters (e.g., terrorist attacks, wars) (Aram et al., 2019; Pascal et al., 2021; Tidball and Krasny, 2013). The results of our study also suggest that planning efforts should focus on increasing investment in parks and green spaces in lower socioeconomic neighborhoods, and this matters for improving the psychological resilience of the lower-income residents and social equity.

Second, this study suggests proximity to parks is important for encouraging neighborhood residents to participate in social and physical activities, thereby protecting their mental wellbeing. This means that planning parks within a neighborhood or within walkable distance from the home is critical for healthy and resilient neighborhoods. In addition to the existing large parks, it is more realistic to infill pocket parks and small green spaces within or near neighborhoods. A recent study has demonstrated the positive impact of pocket parks on improving health and social cohesion during the COVID-19 pandemic (Liu and Wang, 2021). We, therefore, argue that planning efforts on improving green space accessibility should pay attention to pocket parks.

Finally, neighborhood social cohesion was identified as another core element for neighborhood resilience. A cohesive neighborhood environment provides collective and social support for its residents in a disaster. Several previous studies have also concluded that neighborhood social capital largely determines the capacity of communities to cope with and bounce back from a disaster. This includes climate change related disasters, such as heat waves and extreme weather events (Adger, 2003; Browning et al., 2006) and also other natural disasters, including mountain hazards and flooding (Babcicky and Seebauer, 2020).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The data that has been used is confidential.

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