Compact cities and the Covid-19 pandemic

Citation for published version:

Digital Object Identifier (DOI):
10.1016/j.healthplace.2022.102827

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Publisher's PDF, also known as Version of record

Published In:
Health & Place

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Compact cities and the Covid-19 pandemic: Systematic review of the associations between transmission of Covid-19 or other respiratory viruses and population density or other features of neighbourhood design

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ARTICLE INFO

Keywords:
Compact neighbourhoods
Respiratory infectious diseases
Population density
Urban design

ABSTRACT

Living in compact neighbourhoods that are walkable, well connected, with accessible green space can benefit physical and mental health. However, the pandemic raises concern that higher population density may increase transmission of Covid-19, leading some to question the policy of high-density or 15 min neighbourhoods. We conducted a systematic review to identify, appraise and synthesise evidence reporting associations between transmission of respiratory viruses, including Covid-19, and dwelling or population density or other features of neighbourhood design. Twenty-one studies met our inclusion criteria. These studies used differing measures of neighbourhood design, and their findings were inconsistent. No clear conclusion can be drawn about any association between compact neighbourhood design and transmission of infection.

1. Introduction

Urban planning originated in the late nineteenth century as a way to improve population health through improvements in built environments (e.g., sanitation, lighting and ventilation) to combat outbreaks of infectious disease (Corburn, 2012). In recent decades, new challenges have arisen, as car-dominated urban developments and physically inactive lifestyles contribute to the increasing prevalence of non-communicable diseases (NCDs) (Sallis et al., 2016). These NCDs have become increasingly important as the population ages, and include obesity, cardiovascular disease, diabetes and stroke, causing more than 15 million premature deaths per year worldwide (World Health Organization, 2021c). Urban neighbourhoods can influence multiple health determinants such as physical activity (Adkins et al., 2017; Saelens et al., 2003) and mental health (Ige-Elegbede et al., 2020). Over the past two decades, there has been growing understanding of the multiple dimensions through which neighbourhood environments may impact population health and wellbeing, including the mix of people, their lifestyles, community, local economy, activities, built environment, natural environment and global ecosystem (Barton and Grant, 2006; Giles-Corti et al., 2016).

The Covid-19 pandemic has caused significant social and economic disruption and continues to cause morbidity and mortality around the world (World Health Organization, 2021a). Policy responses to the pandemic have included restrictions on mobility, changing how people interact with each other and with their environment. The pandemic, and responses to control it, may bring new implications for urban design. This includes consideration of whether, and how, neighbourhood environments might affect disease transmission, and also how the built environment might mitigate the impact on health of people being asked to stay home, reduce their social interactions and restrict travel (Kang et al., 2022). A better understanding of these factors can allow these to be taken into account in the future policy and design practice.

1.1. Compact cities and health

Almost 50 years ago, based on an ideal of medieval cities, the 'compact city' concept was put forward to increase environmental sustainability, reduce urban sprawl and protect the countryside (Dantzig & Saaty, 1973). The early concept proposed that 250,000 people could live...
in a two-mile neighbourhood with eight-story towers. This would create high residential density in a self-sufficient area with a clear boundary, so that the micro-climate, energy consumption and travel distances could be controlled. Subsequently, the concept was expanded to include centralised activity and intensive land use, to reduce commuting time, car use and greenhouse gas emissions and alleviate resource shortages (Mouratidis, 2018). During that time, low-density urban forms were considered more liveable, leading to a perceived conflict between ‘sustainability’ and ‘liveability’.

Around 2000, the ‘compact city’ was redefined to combine sustainability and liveability (Burton, 2000). A compact city is defined as ‘… intensification of the use of space within the city through higher residential densities and centralization, mixed land uses, limits on development beyond the periphery of the city and efficient public transport and dimensions encouraging walking and cycling behaviours, which may be achieved by an increase in population density, intensive use of buildings, re-use of brownfield and conversion of existing development.” (Wang, 2022, p.24). This has been operationalised in the recent concept of 15-min neighbourhoods in Paris and Shanghai, or 20-min neighbourhoods in Melbourne and Scotland (Tomorrow City, 2022; Shanghai Government, 2016; Victoria State Government, 2018; Scottish Government, 2020). This is an urban design that creates neighbourhoods in which shops, services and amenities are located in local centres, so that residents can meet their daily needs within a 15 min, or 20 min, walk from their home. This requires sufficient density of resident population in each neighbourhood to sustain these services. Nowadays, the concept has been further expanded to include high quality green and open spaces, affordable homes and high quality of services and amenities, to create a walkable, green and sustainable city (Wang, 2022).

The ‘compact city’ provides a good example of potential links between neighbourhood design and health. Unsurprisingly given the focus on walkability, much of the research on compact cities and health focuses on physical activity. A multi-country study of adults in 14 cities found increased physical activity was associated with living in neighbourhoods with higher net residential, intersection, public transport and park density but not mixed land use or distance to nearest public transport (Sallis et al., 2016). A modelling study of six cities (Melbourne, Sao Paolo, Delhi, London, Boston, Copenhagen) predicted reductions in the prevalence of cardiovascular disease, respiratory disease and diabetes would result from a reduction in physical inactivity and reduced vehicle emissions in a more compact urban form (Stevenson et al., 2016). Compact city designs may also bring mental health benefits. Local public space and community venues will facilitate informal and formal social interaction, which benefits mental health (Evans, 2003). Where the compact design includes accessible, high quality urban green space, this should also benefit health as there is strong evidence of benefits to physical and mental health from exposure to greenspace (Kang et al., 2022; Lai et al., 2020).

1.2. Compact cities in a pandemic

The Covid-19 pandemic brings new issues for policy, practice and research. An important consideration is whether, and how, neighbourhood design might impact the transmission of communicable diseases. Covid-19 is caused by the SARS CoV2 virus, which is spread by respiratory particles in aerosols and droplets (World Health Organization, 2021b). It spreads most easily between people in close face to face interaction (Sharifi & Khavarian-Garmsir, 2020). On the other hand, a recent study indicates a protective effect of objectively measured physical activity on Covid-19 transmission (Zhang et al., 2020). This suggests that a compact city that encourages physical activity could help to reduce transmission.

1.3. Review aims

We carried out a systematic review to address the research question: How is transmission of viral respiratory viruses, including Covid-19, affected by population density and other features of compact neighbourhood design? Based on the definition of the compact city, the neighbourhood characteristics in our study included dwelling or population density, housing type, street connectivity or walkability, land use mix and other features of ‘15-20 minute neighbourhoods’. We restricted our review to studies that consider these characteristics at the neighbourhood, sub-city, or city level. The detailed protocol for this systematic review, published on Prospero on October 14, 2020 (ID: CRD42020212949), was developed in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA) (Moher et al., 2009).

2. Methods

2.1. Search strategy

We searched Medline, Embase, Web of Science, Scopus, ASSIA, Avery Index to Architectural Periodicals, Wanfang and CNKI from inception to October 2020 using comprehensive search strategies (Appendix 1). As many studies were conducted in China, we used English and Chinese databases. Studies in the Chinese language were screened by the two Chinese reviewers in our group (XZ and ZS). Colleagues with relevant language skills screened studies in languages other than English and Chinese. Based on predefined eligibility criteria, two reviewers independently screened the titles and abstracts with a third reviewer screening the conflicts. Full text papers were then reviewed independently by two reviewers, and any discrepancies discussed and agreed in a team meeting. Finally, we manually checked the reference lists of included papers and performed forward citation checking for additional relevant studies.

2.2. Eligibility criteria

Eligible studies reported quantitative empirical analyses investigating associations between neighbourhood characteristics at neighbourhood, sub-city, or city level and viral respiratory infectious diseases incidence, prevalence, test positivity, hospital admission, or mortality. Studies excluded from this review were: 1) non-human studies; 2) studies of non-respiratory or non-viral diseases; 3) studies concerned with mobility or effects of social distancing; 7) studies with no measure of transmission; 8) modelling studies; 9) studies not in a high- or middle-income country (see Table 1). We excluded studies from low-income countries because the urban context is likely to differ between high- and low-income countries, and affect the association with transmission.

2.3. Data extraction and management

For each eligible study, we extracted data on details of the study (i.e., first author, year of publication, study design, country, the period studied), neighbourhood (i.e., neighbourhood setting, measures of neighbourhood environment), respiratory infectious disease (i.e., infectious agents type, outcome measured) and main findings (i.e., analysis metric, effect size, covariates included in the analysis). Data were
extracted by two investigators independently and any discrepancies agreed by consensus.

2.4. Data synthesis

Due to heterogeneity, predominantly in exposure and/or outcome characteristics, we conducted narrative analyses. We summarised and compared the neighbourhood and viral respiratory infectious diseases characteristics of each eligible study. Subsequently, we compared the above-mentioned characteristics after categorizing the studies into subgroups based on countries, type of infectious diseases and different measures of a neighbourhood.

2.5. Quality and risk of bias assessment

Two team members appraised each study, with discrepancies in views resolved by consensus. We applied the CASP checklists for cohort and case/control studies. For ecological studies, we adapted a checklist originally from another review (Betran et al., 2015). The checklist consisted of 14 items which included items regarding study design, statistical analysis methods and quality of reporting (Table S1). We graded study quality using the Grades of Recommendation, Assessment, Development and Evaluation (GRADE) system (Guyatt et al., 2008). To do this, we used the approach recommended by Usher Network for Covid-19 Evidence Reviews (UNCOVER): observational studies are given an initial grading of low, then upgraded if multiple studies show consistent results or downgraded if quality appraisal identified the potential for bias in the findings.

3. Results

3.1. Study selection

The database searches identified a total of 2743 articles. After removing duplicates and including articles detected from citation tracking, 1890 articles were screened. A total of 21 articles were eligible for inclusion in the systematic review (Fig. 1). The retained studies were based in the USA (13), China (6), Israel (1) and UK (1) covering Covid-19 (15), influenza (1), SARS (1), lower respiratory infections in children (1), and Haemophilus influenzae in children (1). The Covid-19 studies were all in the first wave of the pandemic, before vaccines were available, when countries were introducing rapidly changing social distancing measures. They considered neighbourhood design features including population density, housing units per building, scale and type, walkability, active commuting, land use mix, school density/proximity, other facilities density/proximity.

3.2. Population density

Population density was the feature of a compact city that was most studied in our included papers, being included in 20 of the 21 studies. Of the studies of Covid-19, eight found a positive association with population density, six a negative association and one found no association. However, several of these were not statistically significant or small effects and the quality of the studies was generally low, often with no adjustment for characteristics of the population that would affect the risk of transmission. All the Covid-19 studies were during the first wave of the pandemic so case ascertainment may have been affected by availability of tests and testing policies. Of the studies of other respiratory infections, six found a positive association and six a negative

Table 1

<table>
<thead>
<tr>
<th>Include</th>
<th>Exclude</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Populations</strong></td>
<td>Human populations – any age, sex or ethnic group</td>
</tr>
<tr>
<td>Condition</td>
<td>Viral respiratory infectious diseases</td>
</tr>
<tr>
<td>Exposure</td>
<td>Studies comparing transmission by aspects of housing/neighbourhood design:</td>
</tr>
<tr>
<td></td>
<td>Dwelling or population density at neighbourhood/city level</td>
</tr>
<tr>
<td></td>
<td>Housing type</td>
</tr>
<tr>
<td></td>
<td>Street connectivity or walkability</td>
</tr>
<tr>
<td></td>
<td>Land use mix</td>
</tr>
<tr>
<td></td>
<td>Features of ‘smart urbanism’ or ‘15-/20- minute neighbourhoods’</td>
</tr>
<tr>
<td><strong>Outcome</strong></td>
<td>Proxies for transmission:</td>
</tr>
<tr>
<td></td>
<td>Incidence, prevalence, test positivity, hospital admission, mortality</td>
</tr>
<tr>
<td><strong>Study type</strong></td>
<td>Studies providing empirical quantitative data</td>
</tr>
<tr>
<td>Context</td>
<td>Studies based in high-/middle- income countries</td>
</tr>
</tbody>
</table>

Fig. 1. PRISMA flow diagram of study selection.
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Setting</th>
<th>Measure of neighbourhood design</th>
<th>Primary outcome</th>
<th>Direction of effect for population density</th>
<th>Effect estimates (95% confidence interval)</th>
<th>Adjusted covariates</th>
<th>Quality (GRADE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryan</td>
<td>2020</td>
<td>Chicago: 795 census tracts</td>
<td>Population density (per mile^2)</td>
<td>Mortality rate – deaths recorded as caused by Covid19 Mar 16th to Jul 22nd 2020</td>
<td>↓ ns</td>
<td>Rate ratio</td>
<td>Population density: 1 (0.0-1.0) % units in buildings with 20+ units: 1 (0.997-1.00)</td>
<td>Age Gender Race Poverty Comorbidity – mortality from heart disease, diabetes, nephrotic, tobacco related Crowded living conditions Transport Work from home Internet access Educational attainment Healthcare access Air quality All at census tract level</td>
</tr>
<tr>
<td>Credit</td>
<td>2020</td>
<td>Chicago: 54 zip codes New York: 177 zip codes</td>
<td>Population density (per m^2)</td>
<td>Confirmed Covid-19 cases per head up to 1^st May 2020</td>
<td>↑ ns</td>
<td>Correlation coefficient</td>
<td>Positive SARS CoV 2 tests per 10,000 and proportion of tests positive up to 22^nd April 2020</td>
<td>Age Race Occupation in Healthcare Overcrowding Median Income Testing rate</td>
</tr>
<tr>
<td>DiMaggio</td>
<td>2020</td>
<td>New York: 177 zip code tabulation areas</td>
<td>Housing density School density</td>
<td>Positive SARS CoV 2 tests per 10,000 and proportion of tests positive up to 22^nd April 2020</td>
<td>↑ ns</td>
<td>Incidence density ratio</td>
<td>population density ns in model, not reported</td>
<td>&gt;65 yrs. Black/African American COPD Heart disease</td>
</tr>
<tr>
<td>Nguyen</td>
<td>2020</td>
<td>US states: 7625 zip codes</td>
<td>Definition of population density not stated Indicators of: Walkability Urban development Physical disorder</td>
<td>Covid-19 cases per 100,000 up to 21^st June 2020</td>
<td>↑</td>
<td>Rate Ratio</td>
<td>population density varies by model, range 1.01-1.04 Non-single-family home: 1.21 (1.16-1.25) Sidewalks: 1.40 (1.34-1.46) Crosswalks: 1.14 (1.10-1.18) Visible wires: 1.08 (1.03-1.13) Dilapidated building: 1.03 (0.99-1.08) Single lane roads: 0.90 (0.86-0.94) Green streets: 0.96 (0.92-1.00)</td>
<td>Age Race Household Size Household Income Poverty Rate Education Civilian employment</td>
</tr>
<tr>
<td>NYU Furman Centre</td>
<td>2020</td>
<td>New York: zip codes</td>
<td>Population density (per mile^3) Housing ≥ 10 units Zip code quintiles based on number of Covid-19 cases per 1000 people on 8th April 2020</td>
<td>Zip code quintiles based on number of Covid-19 cases per 1000 people on 8th April 2020</td>
<td>↓</td>
<td>Population density Highest incidence quintile: 25,082 4th quintile: 20,144 3rd quintile: 29,050 2nd quintile: 47,845 Lowest quintile: 48,067 Percent share of housing ≥ 10 units Highest incidence quintile: 41.7% (±0.6%) 4th quintile: 44.9% (±0.5%) 3rd quintile: 47.7% (±0.5%) 2nd quintile: 71.0% (±0.6%) Lowest quintile: 63.7% (±0.6%)</td>
<td>None</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

(continued on next page)
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Setting</th>
<th>Measure of neighbourhood design</th>
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<th>Effect estimates (95% confidence interval)</th>
<th>Adjusted covariates</th>
<th>Quality (GRADE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cromer</td>
<td>2020</td>
<td>Integrated health care system in Eastern Massachusetts Sample size: 57,865</td>
<td>Population density (not defined) Residential units per building</td>
<td>Positive SARS CoV 2 test: 1st Feb to 21st June 2020 Hospital admission among those positive Deaths among those in hospital</td>
<td>↑</td>
<td>Odds Ratio Population density Positive tests: 1.14 (1.03–1.27) Hospitalisation: 0.99 (0.80–1.24) Deaths: ns not included in full model Housing units per building Positive tests: ns Hospitalisation: &gt;2 units OR 1.83 (1.01–3.31) but &gt;1/3/5/10/20/50 units ns Deaths: ns</td>
<td>Age Sex Race Language Household Crowding Occupation Education Income Transport Testing Rate</td>
<td>Very low</td>
</tr>
<tr>
<td>Emeruwa</td>
<td>2020</td>
<td>New York pregnant women attending Presbyterian/Columbia University Irving Medical Center or Allen Hospital maternity units Sample size: 396</td>
<td>District level population density (no definition) Number of residential units per building</td>
<td>Positive SARS CoV 2 test: 22nd Mar to 21st April 2020</td>
<td>↓</td>
<td>Interdecile Odds Ratio Population density: 0.70 (0.32–1.51) Buildings with more residential units: 0.34 (0.16–0.72) Buildings with higher assessed values: 0.29 (0.10–0.89)</td>
<td>Individual level Comorbidity – diabetes, hypertension Building level: Mean assessed value District level: Household Income Poverty Rate Unemployment Rate Household Membership Household crowding</td>
<td>Low</td>
</tr>
<tr>
<td>Gu</td>
<td>2020</td>
<td>Michigan Medicine health system: people tested and random controls Sample size: 5698 tested, 7168 non tested controls</td>
<td>Population density (1000 Persons per mile²) in census tract of residence</td>
<td>Positive SARS CoV 2 test; Hospitalisation with Covid19 diagnosis ICU admission with Covid19 diagnosis 10th Mar to 22nd April 2020</td>
<td>↑</td>
<td>Odds Ratio Positive test v untested: 1.12 (1.08–1.16) Positive test v negative test: 1.07 (1.03–1.11) Hospitalised v not: 1.10 (1.01–1.19) ICU v not: 1.08 (0.99–1.19)</td>
<td>Age Sex Race BMI Smoking Alcohol Neighbourhood disadvantage score Comorbidity – composite score, respiratory, circulatory, cancer, diabetes, kidney, liver, autoimmune disease</td>
<td>Low</td>
</tr>
<tr>
<td>Vahidy</td>
<td>2020</td>
<td>Greater Houston Sample size: 20,228</td>
<td>Population density (per mile²) of zip code cross tabulation area</td>
<td>Positive SARS CoV 2 test: 5th Mar to 31st May 2020</td>
<td>↑</td>
<td>Unadjusted Odds Ratio Percentile 1 reference lowest Percentile 2: 1.39 (1.22–1.57) Percentile 3: 1.05 (0.92–1.20) Percentile 4: 2.02 (1.79–2.26) Percentile 5 highest: 1.48 (1.31–1.68) GSEM model for race mediated through population density: OR 1.05 (1.01–1.09)</td>
<td>None for unadjusted figures GSEM model adjusted for age and sex</td>
<td>Very low</td>
</tr>
<tr>
<td>Grantz</td>
<td>2016</td>
<td>Chicago - 496 census tracts</td>
<td>Population density (per acre)</td>
<td>Influenza mortality per 1000 From 26 Sep 1918 to Nov 16, 1918</td>
<td>↓</td>
<td>Risk Ratio Mortality: 0.996 (0.994–0.997) Mortality decreased by 4.9% (95% CI = 3.1%, 5.5%) per 10% increase in population density Correlation coefficient For R number: 0.293 (0.249–0.306) p&lt;.001 Weekly R number</td>
<td>Age Illiterate Homeowners</td>
<td>Low</td>
</tr>
</tbody>
</table>

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The third New York study found higher population density ns for 6 of the 7 weeks. Three studies from USA considered respiratory infectious diseases, including from Chicago (Grantz et al., 2016) and influenza hospitalisations, and from New York (Lothrop et al., 2017), deaths from the 1918 influenza pandemic in Chicago (Grantz et al., 2016) and influenza hospitalisations.

Table 2 presents all the studies from USA. Ten of these investigated links between population density and Covid-19. Most of these adjusted for age, sex, and race. They also included co-variates such as measures of poverty or household income, unemployment, education, insurance status, household size, overcrowding, composite measures of neighbourhood disadvantage, working from home and internet access. Although some included comorbidities, others did not. The Covid-19 studies recorded cases in the early stages of the pandemic, with the latest date of testing being July 2020. Early in the pandemic, testing was restricted, so they may have missed people with less severe disease.

Five studies of Covid-19 from USA used an ecological design. Two of these (DiMaggio et al., 2020; NYU Furman Centre 2020) compared zip codes in New York, one (Credit, 2020) considered 54 zip codes in Chicago and 177 in New York, one (Bryan et al., 2020) included 795 census tracts in Chicago, and one (Nguyen et al., 2020) included 7625 zip codes in 20 states. They compared cumulative rates in each area up to a date ranging from April to July 2020. In most studies the outcome measure was confirmed Covid-19 cases, but the Chicago study (Bryan et al., 2020), used mortality, and so only included the most severe cases. Data on cases came from various government, county and state resources, potentially with differing levels of ascertainment. The metrics for analysis differed between studies and included regression coefficient, rate ratio and incidence density ratio. A multi-state study (Nguyen et al., 2020) found a positive association between population density and Covid-19 infection with an estimated rate ratio varying from 1.01 to 1.04. One New York study reported a positive, non-significant association (DiMaggio et al., 2020), another reported a negative non-significant association (Credit, 2020). The third New York study found higher numbers of confirmed Covid-19 cases in areas with lower population density (NYU Furman Centre 2020). However, this was a purely descriptive study so the association may well be confounded by other factors. The Chicago study (Bryan et al., 2020) found an inverse association between Covid-19 mortality and population density. However, after adjusting for statistically associated covariates this association became less significant.

Five studies from USA used individual level data (Table 3), two of which studied pregnant women who were tested for SARS CoV-2 when they attended a labour and delivery unit in New York (n=396) (Emeruwa et al., 2020) or Georgia (n=1882) (Joseph et al., 2020). Results were conflicting, with one finding a positive association with population density (Joseph et al., 2020) and the other a negative association (Emeruwa et al., 2020). These studies only reported bi-variate regression results, so the associations may not persist after adjusting for factors associated with Covid-19 infection. In addition, transmission among pregnant women may differ from transmission among the general population.

The other three individual level studies from USA used the proportion of positive results in people tested in Eastern Massachusetts (n=57,865) (Cromer et al., 2020), Greater Houston (n=20,228) (Vahidy et al., 2020) and Michigan (n=5698) (Gu et al., 2020). All three found a positive association between test positivity and population density. The Massachusetts study (Cromer et al., 2020) reported a fully adjusted OR (95%CI) of 1.14 (1.03, 1.27) and the Michigan study (Gu et al., 2020) reported an OR (95%CI) of 1.07 (1.03, 1.11). The Greater Houston study (Vahidy et al., 2020) concluded that population density indirectly mediated the effect of non-Hispanic Black race (OR (95%CI): 1.03 (1.01, 1.05)) and Hispanic race (OR (95%CI): 1.02 (1.01, 1.06)).

Three studies from USA considered respiratory infectious diseases other than Covid-19, all of which used ecological designs. They studied lower respiratory infections in children under 5 years in Arizona from 2005 to 2009 (Lothrop et al., 2017), deaths from the 1918 influenza pandemic in Chicago (Grantz et al., 2016) and influenza hospitalisations.
Table 3
Studies in China.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Setting</th>
<th>Measure of neighbourhood design</th>
<th>Primary outcome</th>
<th>Direction of effect for population density</th>
<th>Effect estimates (95% confidence interval)</th>
<th>Adjusted covariates</th>
<th>Quality (GRADE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huang</td>
<td>2020</td>
<td>Hong Kong – 291 tertiary planning units</td>
<td>Population density (per km$^2$) Private residential density Commercial density Greenspace density All proportion of land for each use Building height Transport density Land use diversity Sky view</td>
<td>Confirmed Covid-19 cases per 1000, locally transmitted cases only 27 Jan to 14 April 2020</td>
<td>↑</td>
<td>Poisson regression coefficient Population density: 4.00 (0.40) p &lt; .001 Private residential density: 3.21 (0.74) p &lt; .001 Land use diversity – 1.13 (0.19) p &lt; .001 Building height: 0.9 (0.37) p = .015</td>
<td>Geographical features only</td>
<td>Very low</td>
</tr>
<tr>
<td>Liu</td>
<td>2020</td>
<td>Hubei province – 17 cities</td>
<td>Population density (per km$^2$) Covid19 cases per 1000 Up to 16 April 2020</td>
<td>↑</td>
<td>Correlation coefficient R$^2$ = 0.77, P &lt; .005 - all cities R$^2$ = 0.498, P &lt; .005 - excluding Wuhan and Shennongjia</td>
<td>None</td>
<td>Very low</td>
<td></td>
</tr>
<tr>
<td>You</td>
<td>2020</td>
<td>Wuhan – 13 districts</td>
<td>Population density (10,000 persons per km$^2$) Aged population density (per km$^2$) Construction land area proportion Average building scale Public green space density Tertiary industry Retail sales Hospital Density</td>
<td>Confirmed Covid-19 cases per 10,000 people Up to 22 Feb 2020</td>
<td>↑</td>
<td>Spatial Regression Analysis Population density 38.338 p &lt; .01 Aged population density 0.021 p &lt; .05 Construction land proportion 57.859 p &lt; .01 Average building scale – 0.025 p &lt; .01 Public greenspace 2.079 p &lt; .01 (estimates from spatial lag model - rec by authors)</td>
<td>Geographical features only</td>
<td>Very low</td>
</tr>
<tr>
<td>Jin</td>
<td>2020</td>
<td>Chinese neighbourhoods</td>
<td>Facilities within 1.5 km: Restaurant Shopping Centre Hotel Services (Travel Agent, Ticket Office, Job Centre) Recreational Facilities Public Transit Education Health services</td>
<td>Confirmed Covid-19 cases Jan 18 - April 30, 2020</td>
<td>NA</td>
<td>Odds Ratios Restaurant: 2.09 (1.95-2.25) Shopping: 2.27 (2.12-2.43) Hotel: 2.32 (2.16-2.48) Services: 1.82 (1.7-1.96) Recreation: 2.27 (2.11-2.43) Public transit: 1.32 (1.23-1.41) Education: 1.92 (1.83-2.10) Health Service: 4.12 (3.83-4.44) (all higher for cities with population &lt;6 million)</td>
<td>All at city level: Population size GDP Unemployment Residential mobility</td>
<td>Very low</td>
</tr>
</tbody>
</table>

(continued on next page)
between 2007 and 2014 in Tennessee (Sloan et al., 2015). Two of these found a statistically significant negative association with population density (Grantz et al., 2016; Lothrop et al., 2017). The third (Sloan et al., 2015) found a statistically significant increase in hospital admissions for influenza in the highest density areas. However, this study adjusted only for age so the association may be confounded by other factors, including differences between areas in access to community healthcare which is likely to affect hospitalisation for influenza.

### 3.4. China

Table 3 presents all the studies from China included in the review. Four studied Covid-19 but only three considered the association with population density (Huang et al., 2020; Liu, Yuan, et al., 2020; You et al. 2020). All three were ecological studies and they had widely varying units of analysis, ranging in size from tertiary planning units in Hong Kong, with average population size 25,000 people, to cities in Hubei province with a population size between 76,000 and 9.7 million inhabitants. There is likely to be significant heterogeneity of both population density and other characteristics within these areas. All three studies assessed only geographical features without adjustment for the characteristics of people living in each area and found a statistically significant positive association with population density. However, these findings should be interpreted with caution as it is unclear if these associations may be confounded by differences in the characteristics of residents in areas with differing population density.

There were two studies from China of other respiratory infections, investigating influenza H1N1 (Xiao et al., 2014) and SARS (Liang and Mi 2003) respectively. The influenza H1N1 study was a case-control study conducted in municipal districts in Changsha (capital city of Hunan province). The SARS study was an ecological descriptive study, which compared SARS incidence in urban, suburban and far suburban settings. Both studies reported a positive association with population density, but neither adjusted for characteristics of residents in each area, so the

### Table 3 (continued)

<table>
<thead>
<tr>
<th>Author Year</th>
<th>Setting</th>
<th>Measure of neighbourhood design</th>
<th>Primary outcome</th>
<th>Direction of effect for population density</th>
<th>Effect estimates (95% confidence interval)</th>
<th>Adjusted covariates</th>
<th>Quality (GRADE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xiao 2014</td>
<td>Changsha urban area, Hunan Province, China</td>
<td>Population density At street/township level (per Ha in 3 bands) Public places within 1 km: Primary School Middle School Higher Education Places, Hospitals Business District Malls and market</td>
<td>Confirmed flu H1N1 May 2009–Dec 2010 (control is randomly generated space/time point)</td>
<td>↑</td>
<td>Odds Ratios Population density: 2.798 (CI 2.394–3.270 p = .001) for middle density 2.704 (CI 2.108–3.469 p = .001) for high density Places &lt; 1 km: 5.578 (CI 4.65–6.69 p = .001) - higher education places 1.234 (1.046–1.457 p = .013) - middle school 1.417 (1.205–1.667 p = .001) - primary school</td>
<td>Geographical features only</td>
<td>Very low</td>
</tr>
</tbody>
</table>

↑: Increase in effect with increasing population density; ↓: Decrease in effect with increasing population density; NA: not applicable.

### Table 4

Studies in other countries.

<table>
<thead>
<tr>
<th>Author Year</th>
<th>Setting</th>
<th>Measure of neighbourhood design</th>
<th>Primary outcome</th>
<th>Direction of effect for population density</th>
<th>Effect estimates (95% confidence interval)</th>
<th>Adjusted covariates</th>
<th>Quality (GRADE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birenbaum-Carmeli 2020</td>
<td>Israel - all residential communities with population &gt;5000 (approx. 197 municipalities)</td>
<td>Population density (per km²)</td>
<td>Confirmed Covid-19 cases per 1000 Up to 2 June 2020</td>
<td>↑</td>
<td>Regression coefficient 0.00024 - An increase of 100 people per km² raises morbidity by 24 patients per 1000,000 (beta=0.439).</td>
<td>Socioeconomic status Elderly population Minority status (Jewish or Arab)</td>
<td>Very low</td>
</tr>
<tr>
<td>Olowokure et al. (2003)</td>
<td>West Midlands, children &lt;5 yrs.</td>
<td>Resident population per km² by census enumeration district</td>
<td>Hospital admission with lab confirmed invasive H. influenzae - per 100,000 children &lt;5 yrs. 1990–1992 pre-Hib vaccination 1992–1994 post-Hib vaccination</td>
<td>↓</td>
<td>Relative incidence Population density by sextiles, second lowest to highest, reference group lowest density pre vaccination: 1.10 (0.64–1.88); 0.61 (0.34–1.11); 0.69 (0.39–1.22); 0.71 (0.41–1.24); 0.52 (0.30–0.92) p = .0023 post vaccination: 0.93 (0.35–2.47) 0.82 (0.30–2.23) 0.49 (0.17–1.40) 0.63 (0.23–1.73) 0.40 (0.14–1.15) p = .028</td>
<td>None</td>
<td>Very low</td>
</tr>
</tbody>
</table>

↑: Increase in effect with increasing population density; ↓: Decrease in effect with increasing population density; Hib: Haemophilus Influenzae type B.
findings may not be robust.

3.5. Other countries

Table 4 presents studies from countries other than the USA or China. There were only two studies, both ecological. A study of Israeli residential communities (Birenbaum-Carmeli and Chassida 2020) found a positive association between Covid-19 case rates and population density, reporting that an increase of 100 persons per km² raised the Covid-19 case rate by 2.4 cases per 100,000 persons. The study found that population density was positively associated with Covid-19 case rates in both Jewish and Arab communities. It also reported the counterintuitive results that higher proportions of older people and lower socioeconomic status were both statistically significantly associated with lower rates of Covid-19. The authors suggested that this could be because large families with children increased spread of infection. However, as they did not adjust for the child population in their analysis of population density, this is difficult to assess. In addition, a UK study (Olowokure et al., 2003) reported on haemophilus influenza type b (Hib) in children under 5 years in the West Midlands, before and after the introduction of Hib vaccine in the 1990s. Both before and after the vaccine, they found a statistically significant negative association with population density. However, the analysis did not adjust for covariates and may be confounded by other factors.

3.6. Neighbourhood design features

The studies considered a wide range of other neighbourhood characteristics that may be associated with a compact city, including: housing units per building, housing scale and house type; walkability; active commuting; land use mix; density of, or proximity to, schools; density of, or proximity to, other facilities.

Seven studies reported associations with residential units per building, building scale and/or housing type. Four studies from the USA (Bryan et al., 2020; Cromer et al., 2020; Emeruwa et al., 2020; NYU Furman Centre 2020), studied the association between Covid-19 rates and the number of residential units per building. They found either no association or a negative association with the number of units per building (Table 2). The authors of the Chicago study (Bryan et al., 2020) suggested that many affluent residents, who have a lower risk of Covid-19 for other reasons, live in densely populated areas containing multi-unit buildings (Table 2). Two studies from China considered associations between Covid-19 and building scale (You et al., 2020) or building height (Huang et al., 2020), which may indicate higher housing density (Table 3). These reached conflicting results. The USA study of hospitalisations for respiratory infection in children in Arizona (Lothrop et al., 2017) found a positive association with attached homes and mobile homes, but this could be confounded by socioeconomic factors (Table 2).

Three studies, from USA or Hong Kong, considered associations with walkability, active commuting or land use mix and reached conflicting results. The study of zip codes in Chicago and New York (Credit, 2020) adjusted for covariates and found that zip codes with higher levels of active commuting had lower rates of confirmed Covid-19 (Table 2). However, the larger study of over 7000 zip codes across 20 states found that indicators of walkability and land use mix both increased the rate of Covid-19 and single lane roads reduced the rate (Table 2). The Hong Kong study (Huang et al., 2020) found a negative association between land use mix and confirmed Covid-19 cases (Table 3).

Three studies, in USA or China, considered associations with proximity to or density of schools. A New York study (DiMaggio et al., 2020) found no statistically significant association between Covid-19 incidence density ratio and school density (Table 2). Two studies from China (Table 3) used a case-control design with geographical controls to consider the association between proximity or number of educational facilities and either Covid-19 (Jin et al., 2020) or H1N1 influenza (Xiao et al., 2014). The geographical case-control design may cause bias as, given equal risk of infection across the population, highly populated areas that are likely to have more facilities will also have more cases.

Three studies, all in China, studied the association with the density of, or distance to, commercial facilities with inconsistent findings (Table 3). Whereas the Hong Kong study (Huang et al., 2020) found inconsistent associations with the built-environmental variables, the other two studies (Jin et al., 2020; Xiao et al., 2014) found positive associations with all the variables that were included in the study. All three studies have methodological limitations as noted above, so results should be treated with caution.

4. Discussion

4.1. Density and transmission

Taking lessons from history, urban planning and design of built environments have played an important role in the transmission of infectious diseases. For example, John Snow used mapping to identify the pump responsible for spreading cholera, and subsequent improvements to housing and living conditions have reduced the risk of many infectious diseases (Vineis, 2018). Nowadays, some urban built environment characteristics have been identified to have health benefits, such as provision of public transportation, sidewalks, land use mix, green and blue spaces and walkable access to services. However, during the Covid-19 pandemic, some environmental factors such as public transportation hubs have been identified as potential sites of transmission (Liu, 2020; Hamidi et al., 2020).

To our best knowledge, this is the first systematic review that aims to assess the associations between respiratory virus infections (especially Covid-19) and environmental characteristics of a compact neighbourhood design including population density. In theory, living in a compact neighbourhood can bring multiple benefits (e.g., promoting physical activity, increasing social interaction and sharing public facilities), but it might increase transmission during the pandemic, if the higher density increases crowding, especially indoors, or increases the likelihood of face-to-face contact (Sharifi and Khavari-Garmsir, 2020; Rocklov and Sjödin, 2020). Following this concern, we found that studies reported conflicting findings on population and housing density. This could reassure urban designers and policymakers who are promoting compact and walkable neighbourhoods in many international cities, such as the 20-min neighbourhood in Scotland (Scottish Government, 2020) or 15-min neighbourhood in Paris (Tomorrow City, 2020).

It might seem counter-intuitive that higher population density was associated with lower rates of infection in some studies. One reason may be that people in denser, more walkable, neighbourhoods with more local amenities are better able to reduce their wider mobility and comply with social distancing. Two studies (Hamidi and Zandiataashbar, 2021; Chan, 2020) found that during social distancing restrictions, people living in compact areas reduced their journeys more than those in lower density areas. Hamidi and Zandiataashbar (2021) speculated that this may reflect better disease awareness, better internet infrastructure allowing online alternatives, and pedestrian access to essential shops and services in local areas, so that people can avoid large stores where more people gather. People in less densely populated suburban or rural areas may travel into city centres for work, retail and other services, mixing with people outside their area of residence.

Another possible explanation is that living in a compact neighbourhood can encourage physical activity. In Western cities, denser urban areas tend to be more walkable than areas of suburban sprawl (Sallis et al., 2016; Giles-Corti et al., 2016). It has been suggested that physical activity may enhance immunity (Nieman and Wentz, 2019) and therefore reduce susceptibility to Covid-19. For example, a UK study found that objectively measured physical activity reduced the odds of Covid-19 outcomes (Zhang et al., 2020). In addition, our included studies were all in the first wave of the pandemic when restrictions on
testing may have meant that less serious cases were missed. The chronic diseases that are associated with physical inactivity are also associated with higher severity of Covid-19 (Liu et al., 2020; Nystoriak and Bhatnagar, 2018; Nishiga et al., 2020; Crisafulli and Pagliaro, 2020). Plausibly, residents of neighbourhoods that encourage physical activity may have been less likely to have severe disease and so less likely to be tested and receive a positive diagnosis.

Some of these factors vary in different contexts. Most of the studies came from USA or China, which adopted different policy responses to the pandemic. The USA adopted a mitigation strategy. States introduced local mitigation measures including closures of non-essential businesses and schools, which began to reopen again in May. About half of states had introduced mask mandates by August 2020. Testing was more restricted, particularly early in the pandemic (Chen et al., 2021). China adopted a containment strategy with strict lockdown in cities with cases, testing and isolation of cases and contacts (Gao & Zhang, 2021). These differences may impact on how the neighbourhood environment might affect transmission of Covid-19. Also, compared with most studies in western cities, the positive association between high density and physical activity may not apply in the same way in a Chinese context (Sun et al., 2020; Lu et al., 2017). These factors highlight the importance of understanding contextual differences when interpreting these findings.

Apart from population density, several studies investigated other aspects of neighbourhood design that are features of compact cities. These included the number of housing units per building or residential scale, walkability, land use mix, proximity to schools and other facilities, and indicators of quality. There was only a small number of studies that considered each of these characteristics and they mostly reached conflicting findings, so no clear conclusions can be drawn. Other authors have argued that other factors are more important, such as poverty, front line employment, patterns of commuting and household overcrowding (Kang et al., 2020; Hamidi et al., 2020). These may have complex associations with population density and other neighbourhood characteristics, and there are clearer pathways through which these factors can increase the transmission of respiratory infections.

Household overcrowding is an established risk factor for Covid-19 and other infections (Barker, 2020). We did not aim to study household size or overcrowding but several of the Covid-19 studies included household size (Emeruwa et al., 2020; Cromer et al., 2020; Nguyen et al., 2020) or overcrowding (Emeruwa et al., 2020; Bryan et al., 2020; Credit, 2020; Cromer et al., 2020) as covariates, and they all reported a positive association. Housing design features that may reduce transmission include low rise building forms (Mehmed and Ghoneim, 2020), sufficient space to reduce overcrowding and allow home working (Fezi, 2020; Kang et al., 2020; Megahed and Ghoneim, 2020), ventilation (Fezi, 2020; Pinheiro and Luís, 2020), and touchless contact points (Pinheiro and Luís, 2020; Megahed and Ghoneim, 2020). We looked for studies relating to housing form but found limited evidence on this. The Covid-19 studies from USA found either no association or a negative association with the number of units per building but the study of respiratory infections in children, found a positive association with attached homes and mobile homes. The two studies from China of residential building scale or height reached conflicting findings. Taken together, the findings suggest that socioeconomic status is likely to be a more important factor than housing type.

4.2. Limitations of current research

As the Covid-19 pandemic is still ongoing, studies may have prioritised research speed over quality and depth in order to control the transmission, and a major limitation of our review is the overall poor quality of included studies. Most used an ecological design, some of which had a small number of units of analysis. An important limitation was a lack of control for covariates likely to influence Covid-19 rates, including age, socio-economic status and co-morbidity. Some studies set out to identify characteristics of people who had increased susceptibility - for example racial differences - and included few data on neighbourhood characteristics other than population density which was included as a presumed confounder or mediator (Vahidy et al., 2020; Gu et al., 2020; Credit, 2020). Conversely, studies that focused on neighbourhood design often did not control for the characteristics of the people living in different kinds of neighbourhoods. This means that the associations may be confounded, as characteristics of residents of densely populated areas will differ from those living in less densely populated areas. Where included, different measures were used for socio-economic status including median income (Credit, 2020; Nguyen et al., 2020), insurance status (Cromer et al., 2020), the poverty rate (Bryan et al., 2020; Cromer et al., 2020; Nguyen et al., 2020) and composite measures (DiMaggio et al., 2020; Gu et al., 2020; Birenbaum-Carmeli and Chassida, 2020). These different aspects of socioeconomic status may affect the risk of infection in different ways, so it is difficult to compare findings.

Proxies used as measures of transmission included test positivity, reported case rates, hospital admissions and mortality. Many Covid-19 cases are asymptomatic, and severity is strongly influenced by age and comorbidity, so studies using hospital admissions or mortality are particularly prone to bias. In settings without free universal healthcare, high-income people may be more able to afford testing and treatment. Low-income people with minor symptoms may also avoid testing if a positive test would mean losing time off work. Studies may also be biased by geographical access to testing. Early in the pandemic tests were often restricted to hospitals, which are often found in the densely populated centre of a city. This may mean that healthcare workers and their families, who are a high-risk group, are more likely to live in densely populated areas near the hospital. This may be another source of bias.

As we were interested in implications for the ‘compact city’ operationalised into 15- or 20-minute neighbourhoods, we sought studies at the city, sub-city or small neighbourhood level. However, within these studies the population sizes of the units used for analysis varied widely, ranging from 200 households in UK census enumeration districts (Olowokure et al., 2003) to cities or city districts containing millions of people in some of the Chinese studies (Liu, Yuan, et al., 2020; You et al., 2020). The studies also used different indicators for the neighbourhood characteristics of interest, and some did not indicate the measure of population density they used. As several studies reported a high correlation between neighbourhood characteristics, it is difficult to disentangle their effects. The studies used different approaches to analysis and analysis metrics, so we were unable to synthesise results.

4.3. Future research agenda

Research on the links between neighbourhood characteristics and health is complicated by the multi-dimensional nature of these associations. A ‘healthy’ neighbourhood may be defined as being safe, attractive, affordable, environmentally and economically sustainable, socially cohesive, with accessible public open space, employment, education, shops and services, public transport, walking and cycling infrastructure (Badland et al., 2014). These characteristics may interact with each other, and each may affect multiple health determinants. The characteristics of people living in an area affect their health, independently of geographical features of neighbourhoods, but may also interact with elements of design. There is a lack of standard indicators to describe and measure features of neighbourhood environments in studies of their association with health. Studies from different disciplinary perspectives may use different variables and methods, and potentially reach conflicting findings for policymakers. In general, from a geography perspective, scholars often focus on ‘place’, studying the links between environmental factors and health without controlling for characteristics of the population. Public health researchers, on the other hand, focus more on ‘people’ and the demographic characteristics of resident populations with less consideration of environmental characteristics. Moreover, the physical characteristics of neighbourhoods...
change slowly over time making it difficult to plan and conduct longitudinal studies to assess these changes. This means that most available studies are cross sectional, with potential for reverse causality.

Established associations may differ by time period. Some urban design and policy features that are known to benefit health in normal circumstances may need to be re-examined for their impact during the Covid-19 pandemic. These associations may also vary at different time points in the pandemic. Studies of Covid-19 in our review reported findings early in the pandemic. This brings the potential for bias by the kinds of areas that the virus seeded to first, and by differences in testing policies between areas and at different time points. Also, as the world changes in other ways (e.g., new technologies), other environmental factors might need to be revisited to explore their multiple impacts on health in different times.

Most of the studies were from the USA or China. Neighbourhood contexts in these countries differ greatly from each other, and from other countries. There are no consistent definitions for neighbourhood characteristics and variables in the fields of urban planning and design, unlike the definitions in the field of medicine. We speculate that planning and design projects need to face different cultures and societies in different contexts, and scholars also have a different understanding of these characteristics. For example, a city with a 500 million population is a small city in China, unlike the small cities in the UK. However, as Covid-19 is a global issue, if we do not build consistent definitions and terms, we cannot discuss the results and findings from different counties and cities. As such, there is an urgent call in the intersection between public health and urban design for future pandemics. Finally, the current review considered only studies in high- and middle-income countries. There is a need to consider the relevance of the compact city, and to research similar associations with respiratory infections and other health outcomes, in low-income settings.

5. Conclusions

This is the first systematic review we are aware of that has aimed to assess the associations between population density and neighbourhood design and transmission of Covid-19 and other respiratory infections. We found that studies reported conflicting findings relating to population and housing density. Overall, the available evidence provides no clear evidence of either a positive or negative association between population or housing density and the transmission of Covid-19 and other respiratory infections. Several studies investigated other aspects of neighbourhood design that are components of a compact city, including the number of housing units per building or residential scale, walkability, mixed use, proximity to schools and other facilities, and indicators of quality. For each of these, there was only a small number of studies and they reached conflicting findings for most of these characteristics. Overall, no clear conclusion can be drawn about any association between each of these characteristics and transmission of infection.

As society and technology continue to evolve, convenient and fast transportation might accelerate transmission of infectious diseases and facilitate future pandemics’ destructive power and frequency. Future research should use consistent measures and methods to study the links between neighbourhood design and transmission in different contexts and phases. Despite the inconsistent findings in our review, planning policy and urban design can help to reduce transmission – for example by facilitating physical distancing in both indoor and outdoor spaces, reducing the need to travel into crowded city centres by providing local working hubs, and providing sufficient affordable housing to prevent household overcrowding.

Funding sources

None.

Declaration of competing interest

None.

Statements

We published a report on this study on the UNCOVER group website of the University of Edinburgh (Ashcroft et al., 2021).

Acknowledgements

We would like to acknowledge Professor Gerry Fowkes (University of Edinburgh) and the Usher Network for Covid-19 Evidence Reviews (UNCOVER) group, including Dr Ruth McQuillan, Professor Evropi Theodoratou, Professor Harry Campbell, Dr Gwennetta Curry, Professor Harish Nair, and Dr Neneh Rowe-Dewar. For the purpose of open access, the author has applied a Creative Commons Attribution (CC BY) licence to any Author Accepted Manuscript version arising from this submission.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2022.102827.

References


Mouratidis, K., 2018. Is compact city livable? The impact of compact versus sprawled
Gao, J., Zhang, P., 2021. China
Liu, K., Yuan, Y., Liu, Z., Liu, J., Liu, M., 2020. The impact of meteorological and
Evans, G.W., 2003. The built environment and mental health. J. Urban Health 80 (4),
Ige-Elegbede, J., Pilkington, P., Orme, J., Williams, B., Prestwood, E., Black, D.,
Joseph, N.T., Stanhope, K.K., Badell, M.L., Horton, J.P., Boulet, S.L., Jamieson, D.J.,
"worse with social and economic factors in wuhan, China: implications for urban
Haemophilus influenzae disease: an ecological study of sociodemographic risk
factors before and after the introduction of Hib conjugate vaccine. Eur. J. Epidemiol.
Pinheiro, M.D., Luis, N.C., 2020. COVID-19 could leverage a sustainable built environment. Sustainability 12, 5863,
"the associations of walking and cycling: findings from the transportation, urban design, and planning literatures.
Ann. Behav. Med. 25 (2), 80–91,
Sallis, J.F., Gerin, E., Conway, T.L., Adams, M.A., Frank, L.D., Pratt, M., Salvo, D.,
Schipperijn, J., Smith, G., Cain, K.L., Davey, R., Kerr, J., Lai, P.C., Mitka, J., Reis, R.,
Sarmiento, O.L., Schoffel, G., Troebler, J., Van Dyck, D., De Bourdeaudhuij, I.,
Shanghai Government, 2016. Shanghai planning guidance of 15-minute community-life circle. In: Shanghai Urban Planning and Land Resources Administration Bureau,
Sociocultural disparities and influenza hospitalizations, Tennessee, USA. Emerg.
Infec. Dis. 21 (9), 1602–1610,
Stevenson, M., Thompson, J., de Sa, T.H., Ewing, R., Mohan, D., McClure, R., Roberts, I.,
"the associations of walking and cycling: findings from the transportation, urban design, and planning literatures.
Ann. Behav. Med. 25 (2), 80–91,
Hamidi, S., Zandianitabar, A., 2021. Compact development and adherence to stay-at-
home order during the COVID-19 pandemic: a longitudinal investigation in the United States. Landsc. Urban Plann. 205, 103952,
Ige-Elegbede, J., Pilkington, P., Orme, J., Williams, B., Prestwood, E., Black, D.,
Carmichael, L., 2020. Designing healthier neighbourhoods: a systematic review of the impact of the neighbourhood design on health and wellbeing. Cities & Health 1–16, 
Jin, X., Leng, Y., Gong, E., Xiong, S., Yao, Y., Vedanthan, R., et al., 2020. Neighborhood-
Joseph, N.T., Stanhope, K.K., Badell, M.L., Horton, J.P., Boulet, S.L., Jamieson, D.J.,
2020. Sociodemographic predictors of SARS-CoV-2 infection in obstetric patients, Georgia, USA. Emerg. Infect. Dis. 26, 2786,
residential community parks for stress management during the COVID-19 lockdown period in China. Front. Psychol. 13, 816417,
Li, L., 2020. Emerging study on the transmission of the Novel Coronavirus (COVID-19) from urban perspective: evidence from China. Cities 103, 102759,
Lu, Y., Xiao, Y., Ye, Y., 2017. Urban density, diversity and design: is more better for walking? A study from Hong Kong. Prev. Med. 103s, 599–s103,