Exploring the temporal variations in accessibility to health services for older adults: A case study in Greater London

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Abstract

Introduction: Increasing attention has been paid to accessibility and equity during the last two decades. Yet, despite the proliferation of studies investigating accessibility and equity from the perspective of the younger generation, only modest progress has been made in embedding a temporal perspective and targeting health services for older adults. Currently, the number of people over 60s in London is growing rapidly and is projected to increase to approximately two million by 2035.

Aims: This research aims to examine walking accessibility to General Practitioners (GPs) for older people in Greater London, with a particular focus from a temporal perspective.

Methods: Three different datasets were used for this study, namely: GP services data and data on GP Opening Times data from NHS Choices; the London Lower Super Output Area (LSOA) atlas; and the road network derived from OpenStreetMap (OSM). This study uses on the cumulative method to calculate accessibility to GPs – and applies the vertical equity index to measure temporal equity.

Results: Our results show that opening times have a significant impact on accessibility to health services for older people in London. Overall accessibility peaked at midday when 15.88% of areas have a low degree of accessibility. Additionally, our study classifies local authorities into five groups based on their performance on accessibility and vertical equity measurements. We found several districts with inadequate and unequal accessibility that can be identified as vulnerable areas.

Conclusions: Gaining insights into the temporal variations in accessibility to GPs represents a key step towards providing optimal services. Our findings can be used to provide an evidence-based reference for transport planners and policymakers to promote age-friendly development and planning.

Keywords

Accessibility; Health services; Older population's mobility; Spatio-temporal analysis; Equity; Greater London

Highlights

- We examine walking accessibility to General Practices for older people.
- Opening times have a significant impact on accessibility to health services.
- There are five classified groups regarding accessibility and vertical equity measurements.
- Several districts with inadequate and unequal accessibility have been identified.
- Our findings contribute and promote age-friendly development and planning.

1. Introduction

An important dimension of modern healthcare systems is equal accessibility to healthcare services (Mayaud et al., 2019). The extent to which there is equity in terms of access to healthcare services, such as General Practices (GPs), is regarded as a useful evaluation standard of policy performance and social wellbeing. In addition, equity of access to healthcare services is widely acknowledged as an indicator of social exclusion, because health facilities, as an important aspect of community facilities and services, can offer social interaction within the built environment (Ewing and Cervero, 2001). Therefore, much of the existing literature has focused on physical accessibility to healthcare, from the perspectives of accessibility measures (Crawford et al., 2009; Kelly et al., 2016), an assortment of health-related indicators (Tussing, 1983), the association between distance and health outcomes (Field and Briggs, 2001; Thomson et al., 2014), and the level of GP provision (Sexton and Bedford, 2016; Eibich and Ziebarth, 2014). The aforementioned studies have all claimed that better physical accessibility is beneficial to individuals' health.

Demographic ageing has become one of the most notable social phenomena of the modern world. According to a report by the UN (2019), there were 703 million persons aged 65 and over in the world in 2019. Over the next three decades, the older population is projected to more than double, globally, and to reach 1.5 billion in 2050. In London, the number of residents over 60 is projected to increase to approximately two million by 2035 (GLA, 2017). Older people have more frequent and intensive demands for healthcare services. Due to physical constraints and factors relating to their living environment, older people experience a higher risk of social exclusion, which may lead to inequalities in access to healthcare services. Thus, improving the accessibility and equality of healthcare services for older people has become an important policy goal. The WHO (2002) emphasises that healthcare should be within physical reach of all older adults, even in the case of those living in rural areas. The COVID-19 pandemic has also made improving health accessibility more important for older adults.

In addition, because of a number of access barriers (e.g. lack of information, personal mobility, and access to transport) (Allin et al., 2011; Hudson and Nolan, 2015), walking accounts for a greater absolute proportion of the travel modes used by the older population (Feng, 2017), especially when it comes to accessing GPs. Moreover, the existing studies have indicated that walking is the daily travel mode favoured by the largest proportion of older people, particularly in large cities (Cheng et al., 2019; Huang and Wu, 2015). In terms of sociality, as a means of travel, walking is considered to play a major role in maintaining the social participation of the older adults (Cheng et al., 2019; Feng, 2017). Therefore, understanding more about walking accessibility for the older population group can enable interventions to be tailored in a way that can improve their quality of life. Although some older people may choose to use other means of transport, or be limited by the natural environment in some way, they are in the minority. Consequently, it is important to investigate walking accessibility to GPs by older people in order to inform the planning of GPs both in terms of time and space.

Existing studies on accessibility to healthcare services by older people have mainly focused on the spatial dimension and the measurement of physical accessibility, as well as their effects on aspects such as hospital attendance (Turnbull et al., 2008; Layte et al., 2009; Borrescio-Higa, 2015). Consequently, they have the mainly two limitations: first, although the spatial distance dimension has been widely discussed, few studies have considered accessibility to GPs by older people from a temporal perspective. The temporal component is significant in terms of accessibility for the older population, because it is closely associated with the availability of opportunities, services levels of transport modes, and the time availability of individuals (Stępniak et al., 2019). A lack of knowledge about temporal variations in accessibility to GPs could cause biases in understanding the current situation regarding GP provision, and thus hamper attempts to improve the welfare of older people. More data has become available during the last decade, and some studies have attempted to introduce a temporal perspective to examine differing levels of accessibility to various types of opportunities (or services), such as jobs (Boisjoly and El-Geneidy, 2016; Hu and Downs, 2019), grocery shops and supermarkets (Widener et al., 2017; Farber et al., 2014), but few have discussed accessibility to health services or focused exclusively on the older population. Second, the existing literature on healthcare facilities (Allin et al., 2011; Mohan et al., 2019; Hoeck et al., 2013) has rarely discussed the vertical equity of accessibility to GPs or compared the degree of access to GPs for different age groups. Although the ultimate goal of equal access for equal need is regarded as unfeasible (Lovett et al., 2002), gaining a comprehensive understanding of the disparities in accessibility would be a fundamental step towards achieving more equal and age-friendly communities, and therefore facilitate a higher quality living environment.

In order to overcome the limitations of the existing studies, our study, therefore, aims to explore temporal walking accessibility to GPs for older people, using London as a case study. To achieve this goal, this study addresses two questions: 1) What is the temporal variations of GP accessibility in London? 2) Are there significant disparities in GP accessibility between different local authorities, specifically taking the needs of older age groups into account? Using three official datasets, we calculate older people’s accessibility to GPs by the cumulative method, and the vertical equity by applying the Spearman's rank correlation coefficient between the vulnerability index and accessibility levels. In particular, we examine the temporal fluctuations in both accessibility and the vertical equity indicators and use these two indicators to classify local authorities into groups to facilitate more inclusive and tailored practices. This study is not only intended to offer an effective planning channel for the distribution and opening hours of GPs, but also to provide the first-hand evidence that can be used to promote an age-friendly society and overall social wellbeing. Furthermore, the study contributes to the existing literature by elaborating on the criticality of the temporal dimension in understanding accessibility and equity.

The remainder of this paper is organised as follows. Section 2 reviews the accessibility studies with a focus on the temporal perspective and health services. The study area, data and methods used to measure walking accessibility to GPs are introduced in Section 3. Section 4 elaborates on the temporal variations in accessibility to GP services for all, and then specifically for the older population in London at a Lower Layer Super Output area (LSOA) level, as well as examining accessibility and vertical equity at local authority level. The paper concludes with a discussion of significant findings and some suggestions for future research.

2. Literature review

2.1 Temporal accessibility

Accessibility has long been a topic of discussion within the field of transport. Hansen (1959) first brought the concept of accessibility to wider attention and defined accessibility as the potential of various opportunities for interaction, i.e., the ease with which interactions can take place (El-Geneidy et al., 2016; Pereira, 2019). Numerous debates about the definition of accessibility followed (Geurs et al., 2012; Handy and Niemeier, 1997; Le Vine et al., 2013; Morris et al., 1979). Gradually, different interpretations of accessibility were translated into practical approaches and tangible measurements. The most widely used of these are cumulative opportunity measures (also known as isochrones measures), the shortest travel time measure, the gravity measure, the utility measure and the space-time prism model. A detailed review can be found in Neutens' (2015) work.

Although there are many definitions and measurements of accessibility within the research, accessibility can generally be understood as a collection of four components. Geurs and Van Wee (2004) identified the following four components of accessibility: land-use (the distribution of origins and destinations and their characteristics), transport, individual, and temporal. They defined accessibility as the extent to which the interaction between land use and various types of transport helps different individuals to participate in social activities during different periods of time. In other words, accessibility is a function that is dependent on people, transport and land use (social activities) and varies across time. Therefore, there is a family of accessibility measurements that can refer to different combinations of these components, such as the native-born black population and immigrant women’s accessibility to jobs (Parks, 2004); children’s walking accessibility to urban parks (Reyes et al., 2014); accessibility to jobs and education by public transport (Hernandez, 2018); and public transport accessibility to health facilities by vulnerable populations (those aged 65 and over, single-parents and/or low-income households) (Gilliland et al., 2019). Most current research on accessibility analysis has provided greater nuance by subdividing each component into different scenarios, e.g., classifying individuals by various socio-demographic features, categorising transport into different modes of travel (driving, public transport, walking and cycling); and subdividing land use into various key services, such as jobs and education. Järv et al. (2018) provided a detailed summary showing how various combinations of these components have been used in empirical studies of accessibility.

However, empirical studies on the fourth component – time – have only become popular in recent years. Space-time based accessibility (Miller, 1991; Kwan, 1998) can capture heterogeneous social constraints on a person's daily activities and movements in space and time based on the time geographic framework (Hägerstrand, 1970; Neutens et al., 2007; Lee and Miller, 2018). For instance, O'Sullivan et al. (2000) first integrated opportunity-based accessibility and a space-time measure to explore transit-based space-time accessibility in Glasgow. It was found that the travel range shown by isochrones maps varied considerably depending on the departure time of the chosen transportation mode. Similarly, Weber (2003) studied the extent to which the temporal aspect influenced individuals' accessibility to major employment centres in Portland, Oregon, using space-time measures. He argued that the space-time measure was a more realistic one to use for gaining insight into accessibility. It is only in recent years that accessibility has been studied more from a temporal perspective, as the temporal data from various sources have become more widely available (Stępniak et al., 2019). 'Temporal' can be understood, here, as having a threefold meaning: first, the availability of opportunities; second, the availability and service levels of transport modes; and third, the time availability of individuals, i.e., whether people are capable of participating in specific activities, such as work and shopping, during certain time periods. The emerging research can be broadly classified into two types: temporal variability in accessibility (Boisjoly and El-Geneidy, 2016; Hu and Downs, 2019; Moya-Gómez and García-Palomares, 2017; Pritchard et al., 2019); and the impact of temporal resolution on accessibility (Fransen et al., 2015; Stępniak et al., 2019). The distinction between temporal variability and temporal resolution is that: the former used multiple departure times to reflect fluctuations in travel times and availability of services and their impacts on accessibility; the latter used various time intervals (e.g., 1-minute, 10-minute and 1-hour resolutions) to reflect the variations in accessibility. The temporal resolution perspective is particularly important in studying public transport accessibility, as public transport services often vary significantly over different time scales. Stępniak and colleagues (2019) provided a justification for this in their empirical research, stating that the reduction in temporal resolution is associated with a reduction in the accuracy of measuring public transport accessibility. Regarding variability in accessibility, an interesting piece of research by Järv et al. (2018) examined accessibility to food over a 24-hour period in Tallinn, Estonia. By comparing static accessibility and dynamic accessibility, they found that, when the former is used, accessibility tends to be over-estimated and confirmed the importance of incorporating a temporal perspective when studying accessibility. With regard to temporal resolution in accessibility, there was found to be a trade-off between the length of time taken to perform the calculation (higher data requirement) and the granularity of accessibility. Stępniak et al. (2019) applied a hybrid strategy using 5, 10, 15, 30 and 60-minutes resolutions and found that using a 15-minute temporal resolution provides a good balance between precision and computational time. It should be noted that the complexity of temporal accessibility varies on a case-by-case basis. For example, walking accessibility has a weak relationship with the temporal limitations of transport services, as the attributes of pavements do not change dramatically over time. However, in the case of public transport accessibility, the capacities of transport services do change significantly over time. Changes in service performance will directly affect travel costs, such as travel time and fares, and indirectly affect accessibility. Similarly, selecting which time interval is most appropriate to use depends on the context and is strongly limited by time availability.

2.2 Health service accessibility and equity

Accessibility to GP services has been found to encourage the efficient use of health services because of physician-induced demand (Mohan et al., 2019). Depending on whether the measurement of accessibility takes the demand side into account, current research on accessibility can be divided into two types: the measurement of accessibility through utilisation of data purely from the supply side; and the measurement of accessibility by assessing the ratio of residential demand to the supply of healthcare within predefined areas or varying boundary areas. The former is typically based on the measurement of cumulative opportunity, which is simple to compute and requires less data; the latter takes into account the spatial variations within the boundary of a catchment area and the demand-supply interaction across the boundaries, thereby providing more accurate accessibility results but also requiring more data (Luo and Whippo, 2012). An example of this approach is the two-step floating catchment areas method (Luo and Wang, 2003) which has been used in several studies to measure accessibility to health services (McGrail, 2012; McGrail and Humphreys, 2014; Tao et al., 2020). The two-step floating catchment areas (2SFCA) approach comprises the following two steps: the first step identifies all areas that are within the distance of a specified travel cost from the available health services and then calculates the physician-to-population ratio by dividing the capacity of a facility by the number of residents who use it. The second step aggregates all the physician-to-population ratios which are within reach of the population's travel cost. Following Luo and Wang's (2003) method, there have been several advancements in the 2SFCA, such as introducing distance decay functions (Dai, 2010) within the catchment areas; and applying varying sizes of catchment areas (Chen and Jia, 2019).

Increasing accessibility to health services needs to be integrated into health policies, particularly in the case of the older population, because they are more frequent and heavy users of health facilities than other population groups (Hudson and Nolan, 2015). For instance, Kelly et al. (2016) found that there is an inverse relationship between a patient's physical location (usually residential) and their use of healthcare services and/or health outcomes (Kelly et al., 2016). However, although the importance of adequate accessibility to GPs has been acknowledged by the NHS (Iacobucci, 2014), and the topic of health service accessibility has received growing attention in both the fields of transport and public health, studies on accessibility to GPs by older adults are still relatively scarce. The current research on accessibility for older people mainly pertains to green space (Guo et al., 2019; Nicholls, 2001) and specific transport services (Lin et al., 2014). For example, Cheng et al. (2019) investigated walking accessibility to recreational amenities for people over 60 in Nanjing, in China. They found that older adults have lower level of accessibility than the younger generation. Only a few studies have examined accessibility to GPs for older adults and/or vulnerable groups. For instance, Bauer et al. (2018)

studied the spatial accessibility of primary care in England and found that there are substantial differences in accessibility across the country, i.e., approximately 25.8% people lived in areas with a significantly low level of accessibility. Their other counterintuitive finding was that socially deprived areas did not have lower levels of accessibility to GPs than other areas.

The question raised here is why are we particularly interested in exploring accessibility for older groups? The notion of vertical equity is key (Cao, 2019; Litman, 2007), which advocates treating people differently by providing particular discounts and special services for disadvantaged cohorts (Low et al., 2020), such as low income and/or older people. The rationale for doing so is mainly to compensate for overall societal inequalities from a holistic perspective (Cao and Hickman, 2020; Delbosc and Currie, 2011; Ricciardi et al., 2015). By contrast, horizontal equity treats all individuals the same without favouring any specific individuals or groups. Viewed from the perspective of either vertical equity or horizontal equity, social exclusion is not due to a lack of social opportunities, but to a lack of access to those opportunities (Cao and Hickman, 2019; Hine and Grieco, 2003; Hine and Mitchell, 2016; Jones and Lucas, 2012; Preston and Rajé, 2007). This explains why accessibility is widely used as a metric for calculating the level of transport equity at the local or regional level. Recent studies (Cao et al., 2019; Cheng et al., 2020; Guzman and Oviedo, 2018; Lucas et al., 2016) have used the Gini coefficient or index (Gini, 1936) as measurements of transport equity from an egalitarian perspective of social justice. However, as Nazari et al. (2018) argued, the Gini coefficient is unable to capture how changes in equity are related to deprivation. To overcome this, they proposed an alternative criterion – vertical equity – that could be used to assess the association between changes in the vulnerability index and accessibility levels. Using a vertical equity indicator, Deboosere and El-Geneidy (2018) found that vulnerable individuals seem to experience higher levels of accessibility compared to other groups in most cities in Canada. To the best of our knowledge, no previous studies have applied the notion of vertical equity to investigating accessibility to GPs for older adults from a temporal perspective.

3. Methods

3.1 Study area and data

Our case study is based on London. Like most major international cities, London has traditionally tended to revolve around the younger demographic; however, currently nearly 1.1 million of its residents are over 65 and this figure is estimated to increase at an unprecedented rate of 86% - much higher than that of the younger generation - in the next 30 years (GLA, 2018a). With regards to spatial distribution, the older population are more likely to live in Outer London (see Fig. 1). According to statistics produced by Trust for London in 2019, a small proportion of those living in Inner London are over 65 (9.5%), while the figure is 13.9% for Outer London. London is composed of 33 local authority districts (32 boroughs and the City of London) and 4,835 Lower Layer Super Output Areas

(LSOAs). This study measures accessibility at the LSOA level and compares degrees of vertical equity at the local district level.

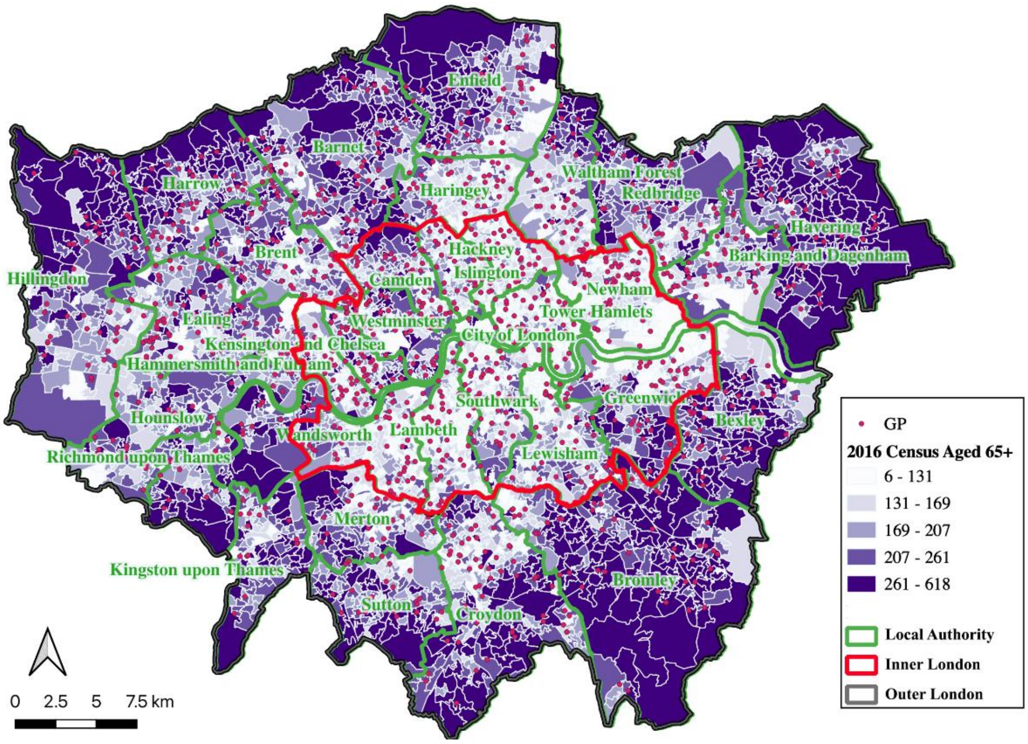


Fig. 1. Study area and the distribution of older adults at LSOA level.

Three datasets were used for this study. The first dataset consists of General Practice services data and General Practice Opening Times data from NHS Choices (downloadable from https://data.gov.uk/search?filters%5Bpublisher%5D=NHS+Choices). Acting as gatekeepers for access to secondary care services (Hudson, 2015), GPs normally treat all common illnesses and refer patients to hospital and other health services for urgent and specialist care. This data consists of geographical information about a list of active GP branches and their opening times.

The London LSOA atlas, which contains demographic data at LSOA level, was retrieved from the Office for National Statistics. An LSOA is a basic geographical unit for which census estimates are provided in England and Wales. An LSOA typically contains 1,000-3,000 residents or 400-1,200 households. London is composed of 4,835 LSOAs, and the average population for each LSOA is approximately 1,700. This study treats 'older adults' as those aged 65 and above (Allin et al., 2011).

The third dataset on the road network was derived from OpenStreetMap (OSM). This contains data about eight types of roads, such as motorways, trunk roads and residential roads. The road network data on different types of roads was prepared for further road network-based buffer generation. In addition, this study also uses geographical London boundary data, and boundary data for 33 local authorities.

3.2 Accessibility measurement

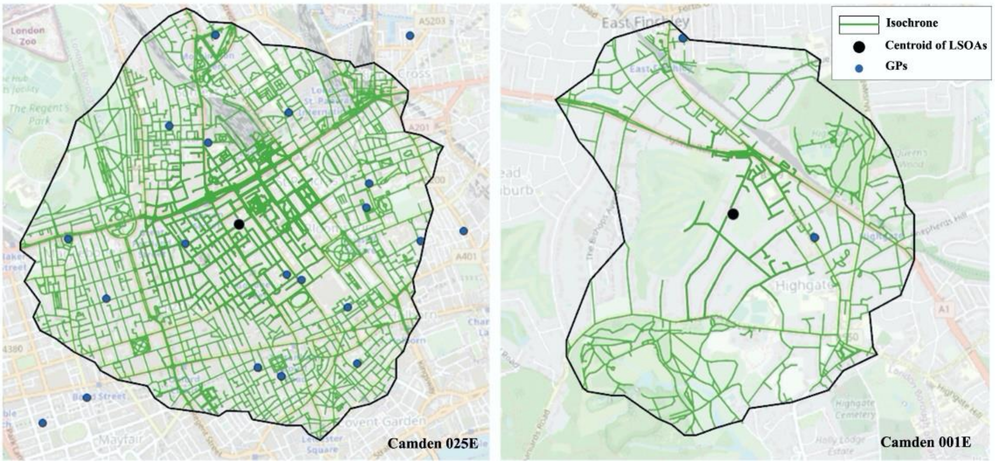
Despite the benefits of the 2SFCA, this study uses a cumulative method to calculate accessibility to GPs, taking 1,200 metres (Xiao et al., 2016) as the walking threshold. The main reason is that there are significant variations between the levels of health services provided by GPs in Greater London. In other words, using the number of GPs instead of the specific number of physicians or other indicators that more accurately reflect the capacity of the health services may to lead potential biases in estimating accessibility in this case. Specifically, we calculated accessibility for every hour on a typical working day (Tuesday). The cumulative accessibility was calculated as follows:

$$A_i = \sum_{j=1}^{n} O_j f(C_{ij}) \qquad (1)$$

$$f(C_{ij}) = \begin{cases} 1 & if\, C_{ij} \leq d_{ij} \\ 0 & if\, C_{ij} > d_{ij} \end{cases} \qquad (2)$$

Where A_i is the accessibility in the census tracts (LSOAs) from zone *i* to all GPs. O_j is the number of GPs available in zone j, and $f\left(C_{ij}\right)$ is an identifier *Equation*. If the travel cost (distance) from *i* to *j* is lower than the specified threshold d_{ij}, then $f\left(C_{ij}\right)$ is equal to 1, i.e., the GPs reachable within the thresholds are counted. If the travel cost (distance) from *i* to *j* is greater than d_{ij}, then $f\left(C_{ij}\right)$ is equal to 0, i.e., the GPs reachable beyond the thresholds are not counted (El-Geneidy et al., 2016).

To capture the walking zones more accurately, we followed Vale's (2018) approach to generate road network-based traffic analysis zones (TAZs). Pedestrian networks were calculated using OpenStreetMap data for LSOA centroids. Compared to using the buffer areas, the road network-based TAZs are capable of more accurately defining the areas that can be reached within the specific walking distance thresholds, especially in areas where there are significant differences in road densities, as previous studies (Frank et al., 2017; Oliver et al., 2007) have found that land use characteristics are more likely to show statistically significant associations with road network-based buffers than circular buffers. Figure 2 shows an example of how accessibility to GPs was measured. The green lines indicate the 1,200m isochrones for two LSOAs (Camden 025E and Camden 001E). From this, it can be seen that Camden 001E has a lower level of accessibility than Camden 025E. This is not only because of the distribution of GPs (represented by blue points), but also due to the relatively low road density. Because of the unavailability of travel behaviour survey data on the older population in London, we applied a uniform distance in order to generate the buffers. However, it should be noted that this approach may result in more inaccuracies than the adaptive threshold approach (Cheng et al., 2019), based on the context-specific data.



(a) Camden 025E (b) Camden 001E

Fig. 2. Example showing how accessibility to GPs is measured.

3.3 The vertical equity measurement

In order to guide practical inclusive accessibility planning for each local authority district, or borough, in London, we calculated a vertical equity indicator to discern accessibility to GPs for older and young cohorts (those aged 65 and over, and those under 65). In contrast to horizontal equity measurements, such as the Gini coefficient (Cao et al., 2019; Delbosc and Currie, 2011; Guzman et al., 2017; Mayaud et al., 2019; Ricciardi et al., 2015) , the vertical equity measure is able to directly reflect the relationship between changes in accessibility and deprivation. In line with the approach adopted by Cheng et al. (2019) and Adli and Donovan (2018), a vertical equity indicator was calculated based on the Spearman's rank correlation coefficient between the rankings of accessibility to GPs and the vulnerability index. In this case, the vulnerability index was estimated using the percentage of older adults (i.e., those aged 65 and above) at LSOA level. The vertical equity indicator (VE, defined in *Eq. 3*) measures those boroughs with the highest need for GPs, as well as those with the highest level of accessibility (Deboosere and El-Geneidy, 2018). In other words, older adults living in boroughs with a low level of vertical equity are likely to have limited access to GPs, and thus need to be prioritised for interventions. The vertical equity index was then calculated for every four hours from 8:00 to 20:00 on a typical weekday to reveal if there were any significant variations:

$$VE^B = \frac{Cov(R_{Acc}, R_{Age})}{\sigma_{R_{Acc}} \sigma_{R_{Age}}} \quad (3)$$

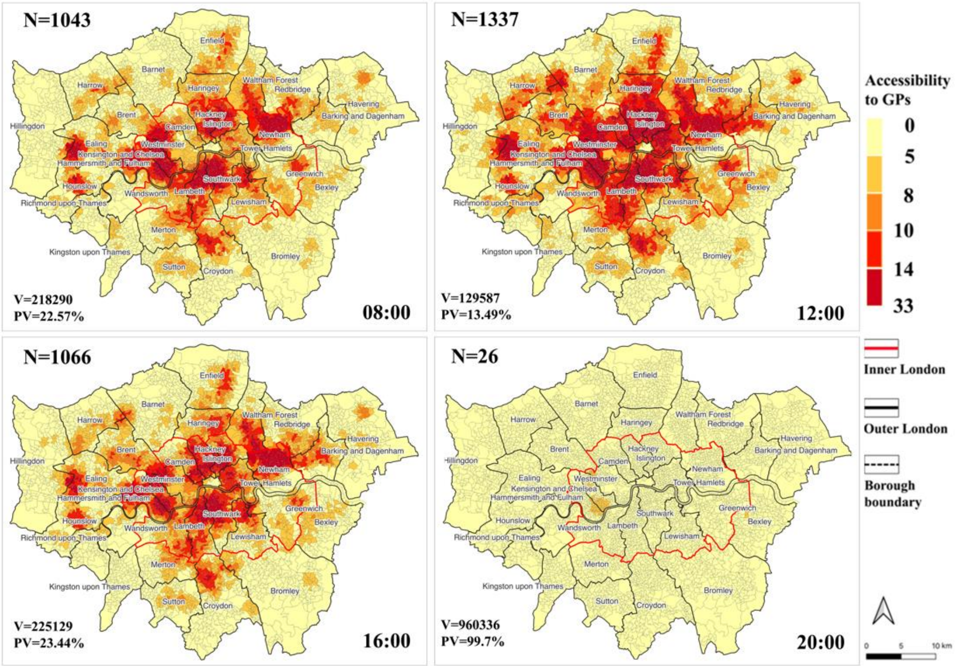
Where VE^B indicates the vertical equity indicator at borough level, and *Cov* indicates the covariance between the ranked accessibility R_{Acc} and the ranked vulnerability index-based on the percentage of older people R_{Age}. The rankings are shown in decreasing order, i.e., the LSOA with R_{Age} of 1 has the highest percentage of older adults within its boroughs, while the LSOA with R_{Acc} of 1 has the highest degree of accessibility within its boroughs. σR_{Acc} and σR_{Age} are standard deviations. The vertical equity indicator measures whether the borough with the highest percentage of older people also has the highest level of walking accessibility to GPs. If the vertical equity is equals to 1, it indicates that the borough with the highest ranking level of accessibility is also the highest ranking in terms of the percentage of the older adults (v) in that borough, compared to other boroughs (i.e. there is an appropriate match between them); whereas if the vertical equity is equals to -1, it means that the borough with the highest ranking level of accessibility ranks lowest with regard to the percentage of older adults (i.e. there is not an appropriate match between them). In the latter case, more interventions are needed to reduce inequalities within the borough.

Because the vertical equity index is a comparative indicator that can only reveal the relative equity between each administrative unit, this study also examined the degree of accessibility and vertical equity. It would not make sense to simply discuss equity in isolation, as higher equity does not necessarily mean that there is greater accessibility to GP services or more opportunities for participation. A min-max normalisation with a 0–1 range was then applied to calculate vertical equity and accessibility at the borough level. In order to inform practical planning more effectively, we classified 33 local districts by conducting K-means clustering (Likas et al., 2003) analysis, based on their normalised vertical equity and accessibility values. In the K-means clustering analysis, the elbow method was applied to select the optimal K number (Bholowalia and Kumar, 2014). This method allows us to use within-group homogeneity to evaluate the variability. In addition, there may be a concern about the vertical equity regarding why accessibility to general practitioners differs between different age cohorts at any particular point in time. The evidence suggests that older adults' understanding of and ability to use hospital reservation technology in the information age puts them at a disadvantage. Additionally, although some GPs may have clinics or GP sessions that are exclusively for older adults, they are the exception rather than the rule, and they are not sufficient to meet the needs of older adults for GP services. Thus, to a large extent, our measurement of vertical equity provides a more accurate reflections of reality and can thus serve our research aim.

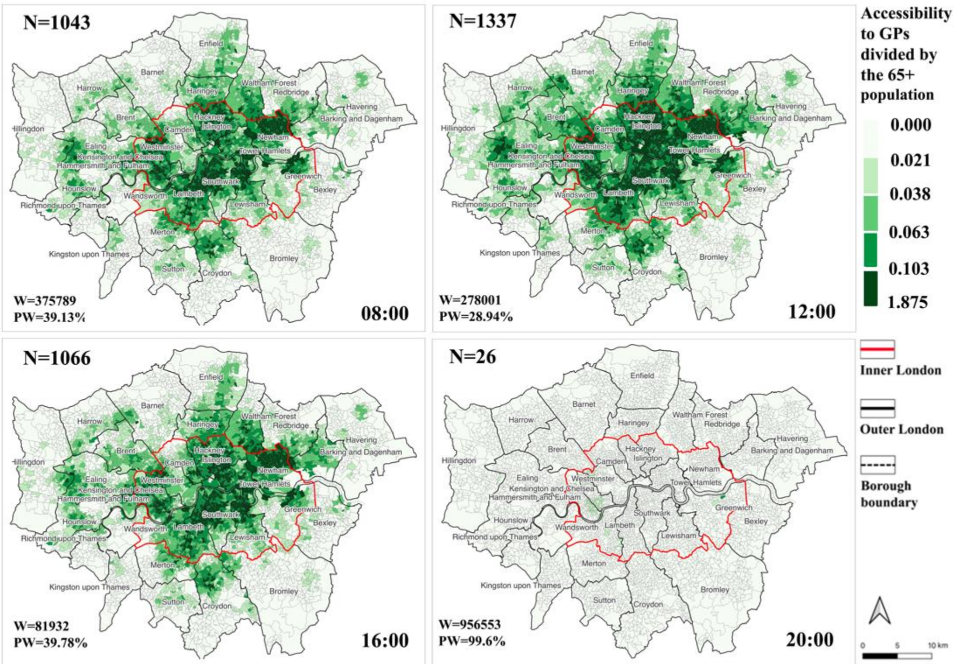
4. Results

4.1 Temporal walking accessibility to GPs

Before discussing accessibility to GPs for older adults in more depth, we first examine the general picture regarding temporal variations in accessibility to GPs in London on a typical weekday. As shown in Figure 3a, there are large fluctuations in accessibility from 8:00 to 20:00. Accessibility is greatest at 12:00 when nearly 15.88% of areas have a low degree of accessibility (below 5). Early in the morning (8 am) and later in the afternoon (4 pm), the figures are 26.08% and 26.10%, respectively. Correspondingly, 13.49% of the older cohort have low accessibility to GPs at 12:00, while a higher proportion – 22.57% and 23.44% - have low accessibility at 8:00 and 16:00, respectively. At 8 pm, 1.63% of local areas offer very limited access to GPs, as only 26 GPs are open and all of those are located in the western part of Inner London. These findings confirm the necessity of taking the temporal perspective into account in order to better understand accessibility. The static measure of accessibility analysis may overestimate accessibility, as it assumes that all GPs are open, when, in fact, this is not the case for London, as our findings show that, even at midday when accessibility is at its highest, not all GPs are open to patients. Furthermore, this research examines the weighted accessibility to GPs, the ratio of accessibility and the number of over 65s in each area. As shown in Fig. 3b, the general varying pattern of weighted accessibility is consistent with the accessibility in Fig. 3a. The weighted accessibility is greatest at 12:00 when nearly 19.50% of areas have a low degree of weighted accessibility (below 0.021). In the early morning (8 am) and late afternoon (4 pm), the figures are 39.13% and 39.78%, respectively. Correspondingly, 28.94% of the older cohort have low weighted accessibility to GPs at midday, while a higher proportion – 39.13% and 39.78% - have low weighted accessibility at 8:00 and 16:00, respectively. By comparing accessibility and weighted accessibility, it can be found that more people in the older age group have limited accessibility to their GPs. For example, at 12:00 p.m., 28.94% of the older population group has lower weighted accessibility, which is almost twice as high as accessibility when the number of older adults is not weighted.



(a)



(b)

Fig. 3. a) Spatial variations in accessibility to GPs during four different time periods on a typical weekday. b) Spatial variations in weighted accessibility to GPs during four different time periods on a typical weekday (N indicates the number of GPs that are open; V and PV indicate the number and the percentage of people in the older age group with a low level of accessibility (<5) to GPs; W and PW indicate the number and the percentage of people in the older population group with low weighted accessibility to GPs (<0.021); The quantile classification of (weighted) accessibility at 12p.m. is used for four time periods. More information about variations in accessibility from 7:00 am to 9:30 pm can be found at GitHub).

With regards to spatial distribution, the areas with higher levels of accessibility are mainly concentrated in Inner London, although there are a few areas in Outer London that also have high accessibility levels, such as several LSOAs in Ealing, Hounslow and Croydon (labelled in Fig. 3a). Focusing now on accessibility to GPs for older adults in London, the boxplot in Figure 4 shows the variations in accessibility during four different time periods on a typical weekday, classified by quantiles, based on the percentage of older residents living in each of the LSOAs. The results show an evident disparity between accessibility for the older population and other population groups. In other words, older people in London are more likely to experience relatively low levels of accessibility, which may lead to social exclusion. More specifically, by comparing the first quantile and the fifth quantile, it can be seen that accessibility in areas with the lowest ratio of older people is roughly 2.1 times higher than for areas with the highest ratio of older residents. This finding can probably be explained by the fact that the majority of older people live in Outer London where the distribution density of GPs is lower.

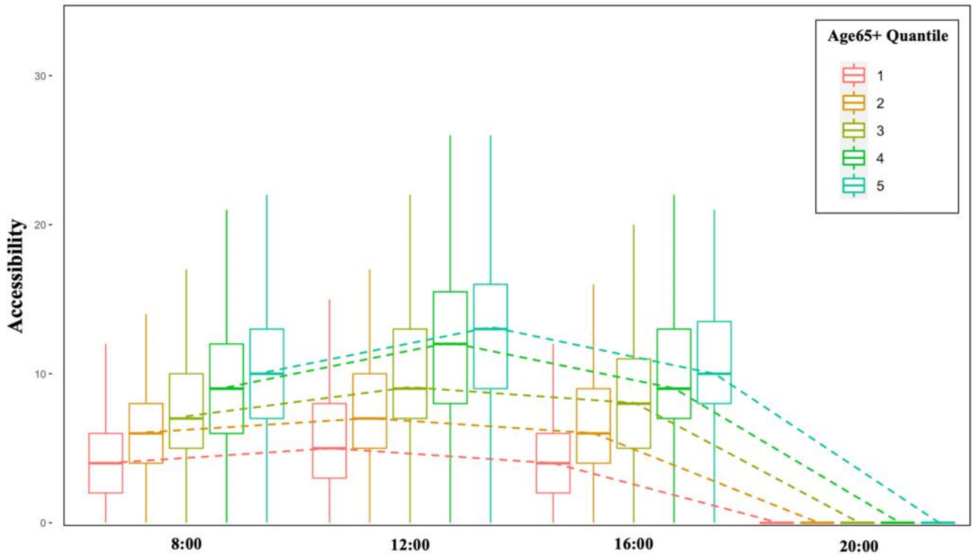
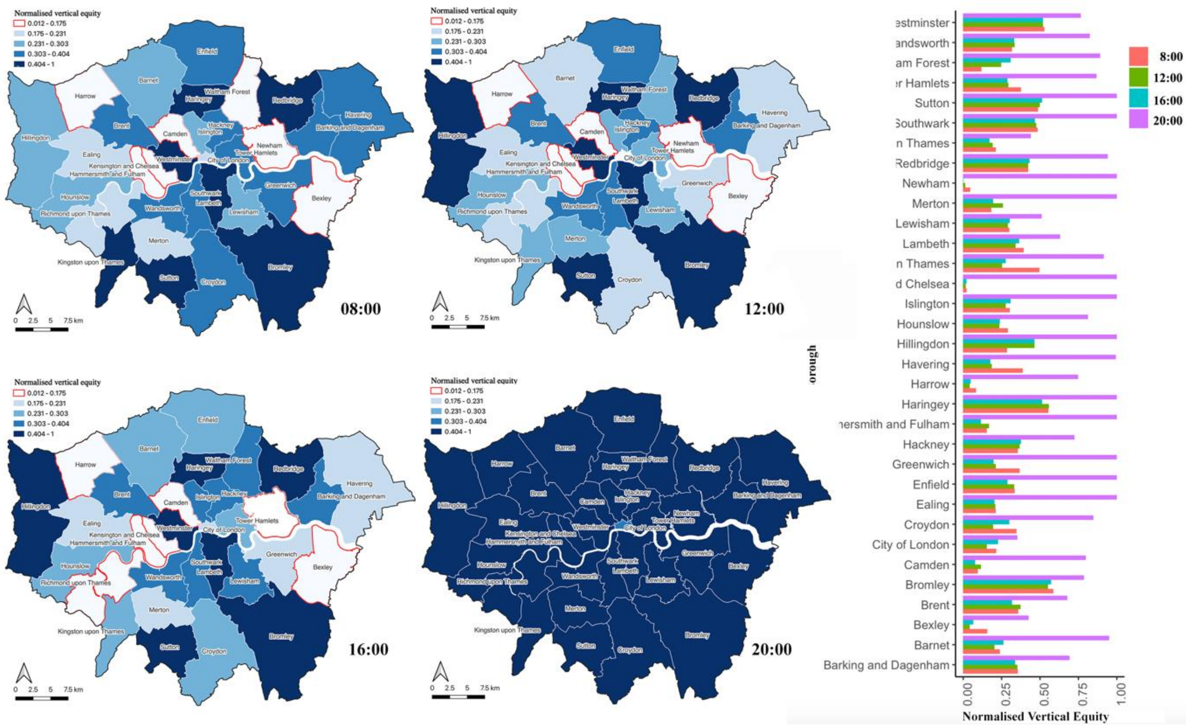


Fig. 4. Variations in walking accessibility to GPs by individuals over 65 during four different time periods on a typical weekday.

4.2 Temporal equity and accessibility

Following the above discussion of varying accessibility levels, we now further examine the temporal variations in vertical equity at local authority district (borough) level and compare how vertical equity changes in relation to accessibility to GPs. Similar to the results for accessibility, vertical equity exhibits changes over time and some districts show substantial changes between 8:00 and 18:00 (see Fig. 5). For example, the degrees of vertical equity for Waltham Forest at 8:00, 12:00 and 18:00 are approximately 0.12, 0.25 and 0.31, respectively. Furthermore, it can be seen that the patterns of variation differ between areas. For instance, some districts, such as Merton, reach their highest level of vertical equity at midday. However, in the case of Tower Hamlets, the highest equity level is reached at 8:00 am and it then gradually decreases until 6 pm. The variations in vertical equity are inconsistent with the findings of Järv et al. (2018) who showed that equity levels for grocery stores in Tallinn remained stable during the day time. Interestingly, but not surprisingly, vertical equity reaches its highest level at 8 pm, after most GPs have closed, and accessibility levels for most boroughs are low. Therefore, we argue that the heterogeneity in equity over different time periods also confirms that the static equity measure may sometimes overestimate or underestimate vertical equity.



(a) (b)

Fig. 5. (a) Vertical equity at London borough level during four different time periods on a typical weekday (The quantile classification of vertical equity at 12p.m. is used for the four time periods**); (b) Vertical equity index.**

As Deboosere and El-Geneidy (2018) argued, the optimal case is the borough located at point (1,1), which represents an area with adequate and equitable health services. This point indicates that older adults would find it relatively easy to access GPs, and that accessibility is evenly distributed between older adults and other population groups. In contrast, the least desirable case is that of the boroughs located close to point (0, 0), where health services are inadequate and inequitable. These boroughs have significant disparities in accessibility between various age groups and a low overall degree of accessibility to health services. To better capture each local district's performance and provide more tailored guidance for future planning, K-means cluster analysis was applied between normalised vertical equity and accessibility. Five clusters were obtained (Fig. 6). For the purpose of discussion, we focus specifically on the clustering results obtained at 8:00, 12:00, and 16:00, given that 20:00 is an exceptional case because most GPs have closed by then. Of the five clusters, districts in Cluster 1 such as Westminster, Sutton and Southwark, perform well both in terms of accessibility and vertical equity. Cluster 2 (e.g., Hounslow and Greenwich) is characterised by a relatively high degree of vertical equity and accessibility. Compared to Cluster 1 and Cluster 2, the other three clusters require more attention and policy interventions from local authorities. Cluster 3 (e.g., Kensington and Chelsea, Bexley) has a medium level of accessibility, but there are significant spatial disparities between the older population and other population groups. Therefore, local authorities need to introduce some more inclusive policies in these areas, such as extending the opening hours of GPs where there is a high concentration of older people. Cluster 4 and Cluster 5 are characterised by relatively high levels of vertical equity and low levels of accessibility. Bromley represents an extreme case where older adults have very limited opportunities to gain access to GPs. There is no statistically significant evidence that shows disparities in accessibility between older population groups and others. In this case, vertical equity seems to be insignificant, as the overall degree of accessibility is relatively low. Therefore, the relevant local authorities should make it a priority to improve overall accessibility to GPs in these two boroughs. The vertical equity and accessibility indicators can be used as a reference for comparing various scenarios and optimising the local distribution of GPs in these districts to create an environment with better accessibility for older adults.

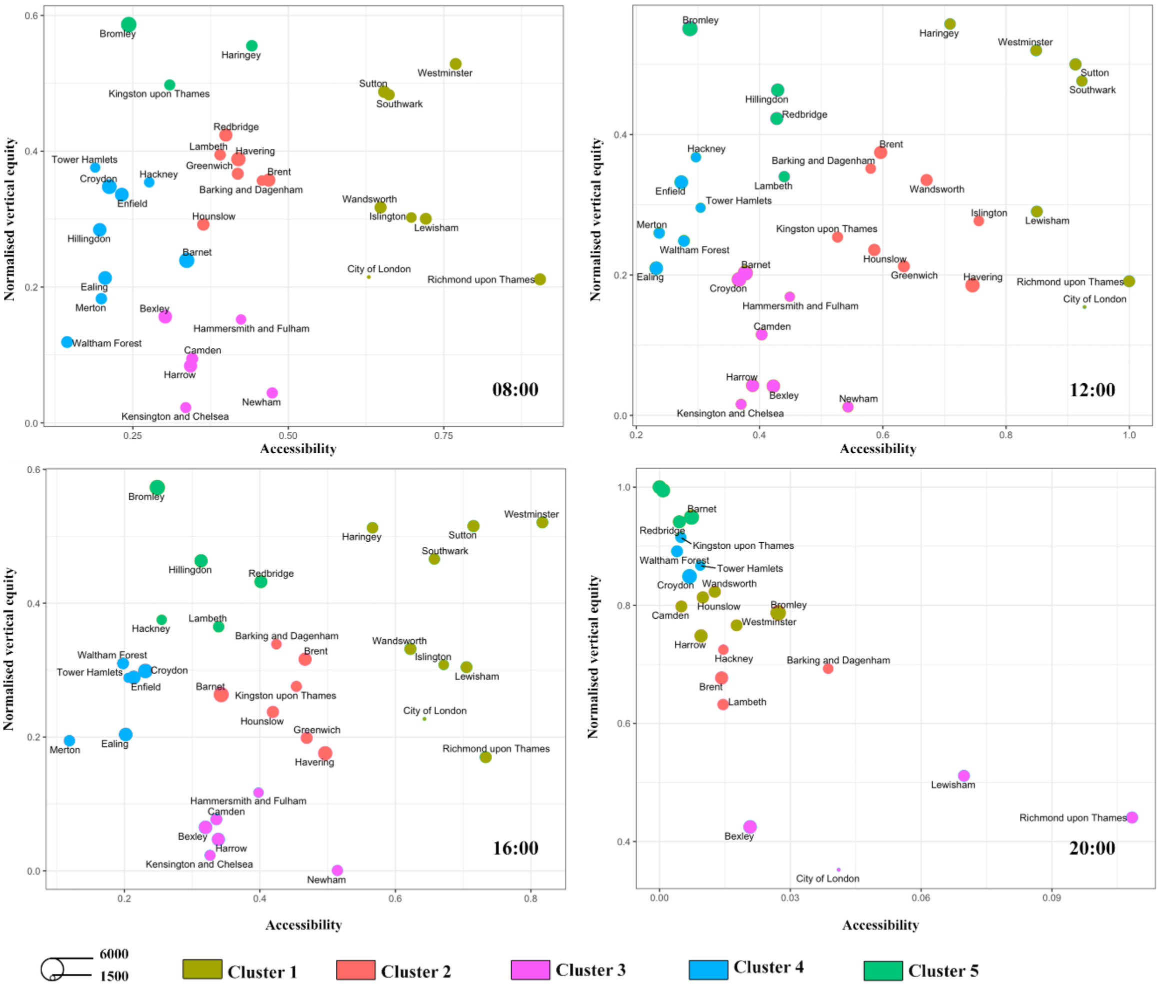


Fig. 6. Temporal variations in vertical equity and accessibility to GPs at local authority district level (circle size indicates the proportion of older people living in each local authority district).

5. Discussion and Conclusions

Since 2013, the NHS has placed much emphasis on the importance of adequate access to GPs (Iacobucci, 2013), particularly for vulnerable groups, such as older people. However, current literature has paid little attention to accessibility to health services, either in terms of accessibility among the older population or from a temporal perspective. This study used the cumulative accessibility approach to investigate walking accessibility to GPs for older adults in London, with a particular focus on the added value of incorporating a temporal dimension into our understanding of accessibility.

This study has four key findings. First, the empirical results revealed large variations in accessibility on a typical weekday in London. Overall accessibility peaked at midday when roughly15.88% of areas have a low degree of accessibility. Second, we found that there were discrepancies in accessibility between older people and others. Accessibility in areas with the lowest proportion of older adults is approximately 2.1 times higher than in areas with the highest proportion of older residents. Third, the vertical equity measure not only revealed a high level of heterogeneity in terms of spatial distribution of accessibility, but also exhibited varying trends over time. Fourth, using

K-means clustering on the vertical equity and accessibility indicators, this study classified the local authority districts into five groups and suggested corresponding policy guidance, especially for those districts that were characterised by a low level of accessibility and significant spatial disparities in accessibility.

The significance and novelty of this study is threefold. First, gaining insights into the spatio-temporal variations in accessibility to GPs represents a key step towards providing optimal services, in terms of spatial distribution and opening hours. This study is the first attempt to examine the temporal variations in accessibility to GPs for older people in London. The first-hand evidence it provides could serve as a robust reference for the Mayor of London and local authorities in their plans to achieve London's health equality plans (GLA, 2018b). More specifically, in addition to spatial distribution planning, there should be a greater focus on temporal planning, such as the opening hours and start times of GP surgeries, both of which will help planners and policymakers to achieve a more equal and healthier city. Second, in line with the existing studies (e.g., Geurs and van Wee, 2004; Boisjoly and El-Geneidy, 2016; Lee and Miller, 2018), our study corroborates that the measurement of accessibility can be sensitive to temporal constraints on opportunities. Therefore, it is necessary to incorporate a temporal perspective into analysing accessibility and vertical equity. The static measures of accessibility that have traditionally been used may overestimate the accessibility, as well as either overestimating or underestimating the degree of vertical equity; thus, merely using the static measurement may lead to possible biases in the findings. Third, in order to inform practical planning more effectively, we carried out a clustering analysis to classify local authorities based on their accessibility and equity levels. Although there is no 'one size fits all' policy, this classification based on vertical equity and accessibility nonetheless offers useful guidance for comparing different types of interventions and optimising the local distribution of GPs. The assessment of vertical equity will also help local authorities to identify those neighbourhoods which are unfriendly towards the health needs of the older population cohort and thus in greater need of GPs, as well as to develop tailored policy packages to promote healthier and ageing-friendly communities.

In particular, more attention needs to be paid to the districts identified as having lower levels of accessibility and significant disparities. This study also provides an example of how a temporal method can be used to examine the accessibility and vertical equity for the older age group. The analytical approach could also be used in other types of accessibility research examining various vulnerable groups, as well as studies set in other UK or even international cities.

We recognise that our analysis has some limitations, as well as areas for further development. First, this study uses the number of GPs as a measure; however, this may not adequately reflect all practical health services available or the capacities of services. Therefore, future studies could use additional measures or proxies, such as the number of NHS staffs or the areas covered by GPs. Furthermore, if the data was available, future research could also include more different types of health facilities, such as clinics and hospitals. Second, it would be more reasonable to integrate the distance decay functions (e.g., Exponential function) into the accessibility estimation to capture how accessibility to GPs changes relative to the walking distance, as the walkers are sensitive to the travel distance (Vale and Pereira, 2018). Furthermore, this study only examined temporal variations on a weekday using a limited temporal resolution. Therefore, a finer grained approach, using temporal variations with smaller temporal resolutions (Stępniak et al., 2020) could be further explored - for instance, variations in accessibility for every half an hour. Third, our research is premised on the assumption that the older adults residing in various areas have the same demand for health services, but, in fact, the utilisation of health services can vary greatly among the older population. It would therefore also be of great interest to consider the dynamic demand for health services among older people (Neutens, 2015) in a future study. Finally, a normative walking distance threshold of 1,200 metres was chosen in this study; however, age heterogeneity within the 65-plus population could play a crucial role, which could be taken into consideration in order to decide on an appropriate walking distance threshold in different contexts in future studies.

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