



# Article The Impact of Built Environment Factors on Elderly People's Mobility Characteristics by Metro System Considering Spatial Heterogeneity

Hong Yang, Zehan Ruan, Wenshu Li, Huanjie Zhu, Jie Zhao and Jiandong Peng\*

School of Urban Design, Wuhan University, Wuhan 430072, China; hyangup@whu.edu.cn (H.Y.); 2017301120067@whu.edu.cn (Z.R.); liwenshu@whu.edu.cn (W.L.); hjzhu1112@whu.edu.cn (H.Z.); whuzhj@whu.edu.cn (J.Z.)

\* Correspondence: 00006709@whu.edu.cn; Tel.: +86-18007133408

Abstract: This study used metro smart-card data from Wuhan, China, and explored the impact of the built environment on the metro ridership and station travel distance of elderly people using geographically weighted regression (GWR). First, our results show that elderly ridership at transfer stations is significantly higher than that at non-transfer stations. The building floor area ratio and the number of commercial facilities positively impact elderly ridership, while the number of road intersections and general hospitals has the opposite impact, of which factors show significant heterogeneity. Second, our results show that the average travel distance of terminal stations is significantly higher than that of non-terminal stations, and the average travel distance of non-transfer stations is higher than that of transfer stations. The distance of stations from the subcenter and building volume ratio have a positive effect, while station opening time and betweenness centrality have a negative effect. Our findings may provide insights for the optimization of land use in the built environment of age-friendly metros, help in the formulation of relevant policies to enhance elderly mobility, and provide a reference for other similar cities.

Keywords: metro; built environment; elderly; travel behavior; spatial heterogeneity

# 1. Introduction

Population aging is a widespread concern in both developed and developing countries. According to the Word Population Prospect 2019, although the global population growth rate will generally show a slowdown in the coming years, the population aged 65 and above is the fastest-growing age group as human health levels rise. The global population aged 65 and older is expected to rise from 11% to 16% by 2050 [1]. Compared with the young population, the elderly population has greater requirements for travel accessibility, convenience, safety, and comfort; thus, the rapid growth of the elderly population poses a great challenge to the organization of urban transportation [2,3]. In the context of an aging society, the organization of urban transportation systems should address the special and complex travel patterns of the elderly; however, this has yet to be widely addressed in existing urban planning [4].

Improving mobility is particularly important for elderly individuals to maintain their health and quality of life [5–7]. Limited mobility prevents older adults from participating in social activities, leading to depression and loneliness [5,8,9]. To encourage the elderly to participate in social activities, many governments offer public transportation discounts. For example, in Wuhan, seniors over the age of 65 can take the subway for free up to 730 times per year, with a 10% discount for additional trips. Unlike most Western countries where elderly people travel mostly by car, public transportation in China is an important mode of travel for seniors in cities with high-density public transportation. Previous studies of elderly travel in metro-oriented cities have emphasized the importance of buses, which are



Citation: Yang, H.; Ruan, Z.; Li, W.; Zhu, H.; Zhao, J.; Peng, J. The Impact of Built Environment Factors on Elderly People's Mobility Characteristics by Metro System Considering Spatial Heterogeneity. *ISPRS Int. J. Geo-Inf.* 2022, *11*, 315. https://doi.org/10.3390/ ijgi11050315

Academic Editors: Wolfgang Kainz and Godwin Yeboah

Received: 8 March 2022 Accepted: 7 May 2022 Published: 19 May 2022

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). a vital mode of public transportation because of their convenience and high coverage [8]. With the increasing coverage of metros, their safety, stability, punctuality, and high capacity make them an important mode of travel for the elderly; however, they have received little attention in existing studies.

Moreover, many studies have showed that the built environment significantly impacts people's metro travel behavior [9–11]. Existing studies have identified that the built environment primarily influences residents' metro travel behavior in terms of the five Ds (5Ds), i.e., density, diversity, design, destinations, and distance [12]. In addition, station characteristics such as betweenness centrality can also impact people's travel behavior [13]. Compared to the younger population, the elderly population is more vulnerable to the built environment due to their declining physical function [3]. However, the specific impact of the built environment is not yet known, and this critical knowledge gap may limit opportunities to mitigate the reduced mobility of older adults due to the increasing aging opulation.

To address this research gap, the impact of the built environment in station-level catchment areas on elderly people's metro travel behavior was explored through a case study of Wuhan, a typical Asian city with an aging population and rapid metro development. By collecting smart-card data and using 5D elements and station characteristics, the characteristics of elderly people's metro travel and the impact of the built environment on metro ridership and travel distance were investigated.

The remainder of the paper is organized as follows. First, the scope of the study, data sources, preprocessing, and research methodology are described. Then, the results are presented and potential policy measures are discussed. Finally, the paper presents the conclusions of the study and suggests future research directions.

#### 2. Literature Review

#### 2.1. Built Environment and Elderly Travel Behavior Associations

The effect of the built environment on elderly people's travel behavior has been proven by other researchers. It has been explained mainly by the 5Ds (density, diversity, design, distance, and distance) [12]. Density (including population and spatial density) is an important factor affecting the travel behavior of the elderly. Existing studies have shown that population density around metro stations has a significant positive effect on ridership at metro stations. In addition, higher densities are usually associated with shorter travel distances [14], which, together with good infrastructure, help in reducing the likelihood of driving while promoting walking and metro travel among elderly adults [15,16]. However, overly high density can increase the insecurity of older adults and thus reduce the possibility of walking [17]. Diversity is mainly expressed through land use mixture. The higher levels of land use mixtures are more conducive to elderly people taking walks or public transportation, as in countries such as Canada, the Netherlands, and China [17–20]. It is reasonable to assume that a higher land use mixture results in the greater spatial proximity of public services needed by seniors on a daily basis, which in turn reduces travel distance and the use of private vehicles while promoting walking and bus and metro trips [21]. In micro-urban design, micro levels such as street connectivity, safety, and network structure can impact the travel behavior of older adults [22,23]. Good lighting, non-slip pavements, and good traffic protection measures help in promoting the possibility of older adults walking, and continuous sidewalks to bus stops and subway stations help the elderly in using buses and subways to travel [24-26]. There is also evidence that the presence of green spaces and stores on both sides of the street is conducive to promoting active travel among the elderly [15,24]. However, some studies have also found a negative effect of neighborhood design on residents' travel patterns [11,27]. Accessibility to destinations has a greater impact on older adults' trips than on those of younger adults [2]. Evidence suggests that the elderly travel more frequently and for longer periods of time if they live near recreational facilities, such as parks, plazas, and green spaces, and facilities for daily needs, such as shopping malls, and they are more likely to adopt walking and cycling to such places [28–31].

The closer the distance to the metro station, the better it is to increase subway ridership. In addition, the higher the coverage of metro stations within a reasonable walking range and the higher the convenience of public transportation connections, the more attractive it is for the elderly to use metro travel [6,32–34]. Therefore, increasing the number of public transportation stations can effectively enhance the use of public transportation among the elderly.

#### 2.2. Effect of Station Characteristics on the Travel Behavior of the Elderly

For metros, the station characteristics of metros also have an impact on residents' travel behavior. Q. Shao et al. found that the betweenness centrality of metro stations was the most important factor influencing ridership and showed a positive impact [13]. Sung et al. found that the accessibility of metro stations has an impact on metro ridership, with the number of entrances being one of the most important factors in promoting ridership [35]. Other researchers added the dummy variables of transfer stations and terminals to the model and found that they could attract more passengers [11,16]. In addition, the efficiency of the use of barrier-free facilities also plays a particular role in this case study, while long walks in stations might prevent seniors from using the metro [36–38].

#### 2.3. Research Gap and Contribution

Existing research has confirmed that the built environment can greatly influence elderly people's travel behavior [12,28,39]. However, most studies on the travel behavior of elderly people have mainly focused on aboveground buses [8,40,41], while only a few have focused on subways. Based on these considerations and with a supporting review of the literature, this study identified six factors that influence elderly people's metro travel behavior: "density", "diversity", "design", "destination", "distance", and "metro station features". With reference to existing studies [17,42], the area with 800 m radius around the metro station was set as the station-level catchment area. In addition, elderly people's metro travel behavior was measured by the number of passengers at metro stations and the average travel distance. These constructs are discussed in more detail in Figure 1.



Figure 1. Research framework.

Having explored the metro travel characteristics of the elderly as a special group and identified the built environment elements that affect the metro ridership of the elderly and travel distance, this study contributes to the existing literature in different ways, fills the existing research gap, and provides a reference for the construction of age-friendly metro systems.

#### 3. Research Design

# 3.1. Study Area

The study took place in Wuhan, the capital of Hubei Province in Central China. Since 2010, the population over 60 years old in Wuhan has been growing at an average rate of more than 50,000 each year. By the end of 2018, 1,879,400 people aged 60 years or older accounted for 21.27% of the total population, exceeding the Chinese average by 3.4%, and had entered the ranks of superaged cities. Divided by the Yangtze River and Hanshui, Wuhan is a conglomeration of Wuchang, Hankou, and Hanyang. Further, Wuchang includes Wuchang district, Qingshan district, Hongshan district, and Jiangxia district. Hankou includes Qiaokou district, Jiang'an district, and Jianghan district, as shown in Figure 2. The spatial pattern of Wuhan is mainly bounded by the urban development area and the Third Ring Road, generally divided into suburban areas and core areas. The core areas have a dense population and the highest travel intensity. The suburban areas of the city are developing rapidly, and the intensity of travel is growing faster. Wuhan's unique "narrow cross-section, strong agglomeration" characteristics determine the popularity of metros in the city. On October 24, 2018, the cumulative ridership of the Wuhan metro exceeded 4 billion trips, with an average daily ridership of over 3 million trips. The role of the metro has been further developed, and it has become one of the most important modes of daily travel for Wuhan residents.



Figure 2. Location map of Wuhan.

## 3.2. *Methodology*

This study attempted to explore the influence of station-level catchment areas on elderly people's metro travel behavior. As metro stations and built environment factors are spatially clustered and heterogeneous, the built environment has different local effects on metro ridership and travel distance. A geographically weighted regression (GWR) model was used for the analysis in this study. GWR was used to explore the spatial variation at a certain scale and with related drivers by establishing local regression equations at each point in the spatial range. It embedded spatial structure into the model, and its regression coefficients were a function of spatial location. Equation (1) shows the mathematical expression of the GWR model [43]:

$$y_i = \beta_{i0}(u_i, v_i) + \sum_{k=1}^p \beta_{ik}(u_i, v_i) x_{ik} + \varepsilon_i, \text{ I} = 1, 2 \dots, \text{ n}$$
(1)

where  $(u_i, v_i)$  is the coordinates of station i;  $\beta_{i0}(u_i, v_i)$  is the estimated intercept of the *i*th site; P is the number of independent variables, which in this study is 142;  $x_{ik}$  is the k-th independent variable of the *i*th site;  $\beta_{ik}(u_i, v_i)$  is the regression parameter of the independent variable  $x_{ik}$ ; and  $\varepsilon_i$  is the random error of the *i*th site.

In this study, the Gaussian function was used to calculate the spatial weighting matrix, and the expression is Equation (2):

$$y_{ij} = \exp\left[-(d_{ij}/b)^2\right], j = 1, 2 ..., n$$
 (2)

where  $d_{ij}$  is the distance between the *i*th site and the *j*th site and b is the bandwidth.

Considering that categorical variables can affect the accuracy of analysis, two categorical variables of whether the station was the terminal or a transfer station were taken into the Mann–Whitney U test to explore their effects on the dependent variable. In addition, continuous variables may have multicollinearity, so stepwise linear regression was used to screen them, and then the retained variables with significant effects were brought into the GWR model for analysis.

#### 3.3. Data Sources and Description

The data used in this study included Wuhan metro smart-card data in March 2018, Wuhan population data in 2018, point of interest data (POI) of Wuhan in 2018, and Wuhan land use vector data in 2016.

Among them, the card data were obtained from the Wuhan Transportation Development Strategy Institute, which recorded the card holder's card number, entry number, and time of entry. The card types included the elderly, disabled, primary and secondary school students, and general tickets. This study extracted the card data of elderly people according to the card types. The population data were obtained from the Wuhan Land Use and Urban Spatial Planning Research Center, which recorded the number of people of different age groups in each community unit. POI data were obtained from AMAP, which covers different spatially geographic information (latitude and longitude, detailed address) as well as specific facility names, major categories, and other attributes. The land use data were obtained from the Wuhan Planning and Design Institute, which were different from other data of the related year, but their main use was to calculate the land use mixture degree. Considering the lag effect of metros on urban land use, the effect of using these data on the results can be ignored. In addition, the use of official vector data can guarantee the accuracy of the results compared to the data obtained by other methods, such as satellite remote sensing. The descriptive statistics of the built environment within the study area are given in Table 1.

In this study, the dependent variables were elderly ridership and travel distance. Ridership is mainly concentrated in the Hankou riverside area, Wuchang core area, and Hanyang riverside area, as shown in Figure 3. Among them, the Hankou riverside area is the most concentrated area of commercial facilities, medical facilities, and parks in Wuhan and the most concentrated area for elderly people to travel by metros, while the Wuchang core area and the Hanyang riverside area are the most concentrated areas of commercial areas. This indicates that elderly people's travel is largely influenced by commercial, medical, and park areas [28,30,31]. In terms of travel distance, according to previous findings, metro travel for the elderly is dominated by short- and medium-distance travel. From Figure 4, it can be seen that the percentage of people who traveled 0–10 km was 70.30%, and the percentage of people who traveled more than 20 km was less than 3% [44,45].

Category	Variable	Variable Description	Average Value	Standard Deviation
Density	Elderly population density	The ratio of resident elderly population to station area (persons/km <sup>2</sup> ) was calculated by Kriging Interpolation	681.86	287.38
Density	Building Floor area ratio	The Building Floor area ratio of the area around the metro station was calculated from the building vector data of Wuhan	0.87	0.65
Diversity	Degree of land use mixture	The degree of land use mixture within the catchment area of the URT station. Landus = $\frac{\sum_{i=1}^{k} P_{ki} l^{(n)}(P_{ki})}{\ln k}$ , where <i>k</i> is the number of land use types in the area around site <i>i</i> and $P_{ki}$ is the proportion of the area of the <i>k</i> th type of land use in the area. A larger <i>landuse</i> value indicates a higher land use mixture, while a smaller one indicates a lower land use mixture	0.72	0.12
Design	Number of intersections	Number of intersections in the station area of the metro station, representing the road complexity	26.58	17.48
	Number of general hospitals	Number of general hospitals in the station area of the metro station	27.11	27.02
Destination	Number of parks	Number of parks in the station area of the metro station	1.09	1.71
	Number of commercial facilities	Number of commercial facilities in the station area of the metro station	203.02	275.37
	Distance from the city center	Euclidean distance between the URT station and the city center (km)	10.64	6.20
Distance	Distance from the sub city center	Euclidean distance between the URT station and the nearest sub city center (km)	6.30	5.55
	Number of bus stops	Number of bus stops in the station area of the metro station	5.96	5.03
-	Station area road length	Length of road within the station area of the metro station	11.57	3.69
	Betweenness centrality	The betweenness centrality: $C(u) = \sum_{s \neq u \neq t} \frac{\partial_{st}(u)}{\partial_{st}}, \text{ where } \partial_{st}(u) \text{ is the}$ number of shortest paths between station node s and node t and $\partial_{st}(u)$ is the number of shortest paths that pass through node u	0.41	0.09
- Metro station features -	Terminal	Dummy variables, where 1 means the station is the terminal and 0 means the station is not		
	Transfer station	Dummy variables, where 1 means the station is a transfer station and 0 means the station is not		
	Exit quantity	Number of exits of the URT station	5.08	3.49
	Station opening time	The length of time after the metro station is put into use (months)	71.85	59.81
	Barrier-free facilities and indication system	Include: whether there is a ramp; whether the ramp is available; whether the barrier-free straight stairs are available; whether there is a barrier-free indication system, etc. 1 means yes; 0 means no	0.79	0.41

# Table 1. Description of the variables.



Figure 3. Distribution of metro travel direction for the elderly.



Figure 4. Distribution of metro travel distance for the elderly.

### 4. Results

4.1. GWR-Based Analysis of the Factors Influencing the Metro Ridership of the Elderly

The results of the Mann–Whitney U test on the categorical variables show that transfer stations make a significant difference in rail traffic for the elderly, with significantly higher traffic at transfer stations than at non-transfer stations. The results are shown in Table 2, which are consistent with the results of previous studies on other populations [13,27,46]. Central optimization of transfer stations promotes metro travel for the elderly.

Table 2. Non-parametric test results for the "transfer station".

Transfer Station	Median	Z	p	Significance
Yes	101.09	3.670	< 0.001	***
No	66.08			
Note: *** $m < 0.01$				

**Note**: \*\*\*  $p \le 0.01$ .

Table 3 shows the results of stepwise regression on continuous variables. It indicates that the building floor area ratio, number of commercial facilities, number of intersections,

and number of general hospitals had a significant effect on the ridership of the elderly. Unlike the findings with other population groups [9–11], the population density of the elderly did not show a significant correlation with ridership, mostly because the elderly who traveled by metros were predominantly of a lower age (60–69 years old, still in good health), and the data limitations prevented a further breakdown of the data, which in turn may have affected the analysis results. Additionally, the land use mixture did not show a significant correlation because a higher land use mixture is more conducive to more diverse services and crowded activities but does not effectively promote the mobility of the elderly. This is because crowds may lead to psychological discomfort among the elderly and impact their travel safety [18]. Additionally, accessibility did not show a significant correlation, probably because all metro stations in Wuhan are already equipped with accessibility facilities.

¥7 1-1 -	Non-Standardized Coefficient		Standard Coefficient	TT \$7-1	u Value	Significance
Variable	В	Standard Error		1-value	<i>p</i> -value	Significance
Intercept	104,322.487	23,679.750		4.406	< 0.001	
Building Floor area ratio	154,444.831	32,207.068	0.613	4.795	<0.001	***
Number of commercial facilities	380.141	75.534	0.644	5.033	<0.001	***
Number of road intersections	-2997.383	989.389	-0.322	-3.030	0.003	**
Number of general hospitals	-2363.382	846.822	-0.393	-2.791	0.006	**

Table 3. Significant variables and regression results affecting the metro ridership of the elderly.

**Note**: \*\*\*  $p \le 0.01$ ; \*\*  $p \le 0.05$ .

The above four variables were used to construct regression models using ordinary least squares (OLS) and GWR, and Table 4 shows the comparison of the fitting results of the two methods. The fitting results of GWR were optimized by 12% compared with the results of OLS, the value of AICc was also smaller, implying that simulation accuracy was significantly improved, so the results of this study using GWR were more appropriate. To facilitate the comparative study, the effects of each of the above elements on the ridership of the elderly were spatially visualized.

Table 4. Comparison of fitting results between OLS and GWR.

Model	Residual Sum of Squares	Coefficient of Determination	Adjusted Coefficient of Determination	AICc
OLS	1,153,472,615.0217	0.4663	0.4467	2674.8514
GWR	714,913,944.7844	0.6692	0.5670	2662.9593

(1) In general, building floor area ratio has a significant positive effect with elderly metro ridership, which is consistent with existing studies that dense development is more favorable for residents to travel by metro [13,47]. Specifically, its impact shows a spatial distribution trend of gradually increasing from core urban areas to peripheral urban areas, as shown in Figure 5a. Among them, the Hankou and Wuchang riverside areas are the least affected areas. These areas are the areas with the highest concentration of elderly people in Wuhan, but they are also the areas with the highest housing prices. Based on previous studies, it is known that residents' income is an important factor affecting their travel patterns. The higher the income, the higher the proportion of private car ownership and the more likely it is that private car trips are taken. The study by Huang et al. [48] also shows that the construction of the metro will prompt residents to switch from other travel modes to metro trips, but this has less impact on those who own private cars. Meanwhile, the above areas are also the areas with the highest density of public transport stations in

Wuhan, which has a more significant diversion effect on metro ridership. In addition, these areas are the most concentrated areas of the Wuhan city landscape with various public service facilities, and some elderly people living in these areas can reach the facilities by walking. Therefore, the building density in this area has less influence on metro ridership. However, the building volume ratio outside the Second Ring Road and near the Third Ring Road in Hankou has a greater impact on the elderly's metro travel. This is due to the lower density of the surface road network and more serious traffic congestion in this area, which makes the metro relatively more attractive to the elderly. This corresponds to the findings of some previous studies that the higher the density of the roads around the subway stations, the more favorable it is for residents to travel by rail [49,50].

(2) The number of commercial facilities also shows a significant positive effect on the ridership of the elderly, which is consistent with the results of many studies [10,47,51,52]. However, from Figure 5b, it can be seen that the impact of commercial facilities on elderly ridership differs significantly among the three areas of Wuhan. Hankou shows a significant positive impact overall, while Wuchang and Hanyang show a negative impact overall. The reason for this result is most likely due to the urban function of Wuhan city. Hankou is the commercial core of Wuhan, while Wuchang is the political, educational, and cultural center, and Hanyang is dominated by industry and housing. This is consistent with the findings of Gan et al. [10] based on Nanjing, where the relative importance of commerce is much higher than that of industrial and residential land uses in terms of its impact on metro ridership. In addition, both Wuchang and Hanyang have low metro coverage, resulting in low network accessibility, corresponding to Peng et al.'s study [53], which showed a significant positive effect of network accessibility of metro stations and metro ridership. Therefore, the impact of commercial facilities on elderly metro ridership in the region shows a negative effect in general. However, there are differences in the reasons for the low metro coverage; Wuchang is divided by natural lakes, while Hanyang has a backward construction schedule. Therefore, it is important to accelerate the construction of the metro line network in the Hanyang area to relieve ground traffic pressure and promote metro travel for the elderly.

(3) Road intersection density showed a significant negative effect on elderly subway patronage overall, which is different from the results of studies such as Durning and Townsend [50] based on all Canadian populations. The reason for this difference may be that the elderly population places more importance on road safety due to their specific physical characteristics. From Figure 5c, it can be seen that the areas where road intersections show a negative impact on elderly ridership are mainly concentrated in the core area within the Second Ring Road, where motor vehicle traffic is higher and traffic-light waiting time is longer. It means that elderly people will face more risk and take more time to reach the stations, so the elderly rail transit station travel flow in this area shows a significant negative impact. In contrast, outside of the second ring core, the number of roadway intersections shows an overall positive effect on rail trips for seniors. This is because the higher the density of intersections, the higher the accessibility to the metro stations. As the motor vehicle flow is lower and the waiting time for traffic lights is shorter outside the Second Ring Road, it is more favorable for the elderly to walk to the stations, thus encouraging the elderly to travel by metro.

(4) Unlike other public service facilities that significantly contribute to metro locations, the number of general hospitals shows an overall negative impact on ridership among older adults. Existing studies have suggested that the impediment to metro travel for the elderly is the built environment, not the cost [2]. In addition, the studies point out that the built environment is likely to be doubly dangerous for elderly people with illnesses, which in turn leads them to use other, safer modes of transportation for medical care [54]. However, as shown in Figure 5d, general hospitals in some areas of Hankou show a positive effect on elderly ridership. The reason for this phenomenon is that Hankou has the most concentrated area of medical resources in Wuhan, with several prestigious hospitals—Tongji Hospital, Xiehe Hospital, and PLA 161st Hospital. Due to the specialties of the hospitals, parking for

social vehicles is prohibited in some parts of the area. In addition, a metro station is located at the entrance of the hospitals, which has a significant positive impact on the ridership of the elderly in this area. In addition, in some areas outside the Second Ring Road and the Hanyang area, due to the relatively backward construction of medical facilities and low aboveground bus coverage, the area where the general hospital is concentrated also has a more significant positive impact on ridership.



**Figure 5.** Spatial variation in the impact of different built environment elements on metro ridership of the elderly.

# 4.2. GWR-Based Analysis of the Factors Influencing the Metro Travel Distance of the Elderly

The results of the Mann–Whitney U test (seen in Tables 5 and 6) on the categorical variables showed that the factors of whether the station was a terminal and whether it was a transfer station had significant differences in the travel distance of the elderly, with the average travel distance of terminals significantly higher than that of non-terminals, and the average travel distance of non-transfer stations being significantly higher than that of transfer stations [11,17].

Table 5. Non-parametric test results for "terminal".

Terminal	Median	Ζ	p	Significance
Yes	110.60	3.118	0.002	**
No	68.54			

**Note**: \*\*  $p \le 0.05$ .

Transfer Station	Median	Z	p	Significance
Yes	49.59	-2.717	0.007	**
No	75.52			

Table 6. Non-parametric test results for "transfer station".

**Note:** \*\*  $p \le 0.05$ .

The results of stepwise regression on continuous variables (Table 7) show that the distance of stations from subcenters, station opening time, betweenness centrality, and building floor area ratio have significant effects on travel distance for the elderly. Unlike the findings in other cities [55], the distance to urban centers did not have a significant effect on travel distance for the elderly because Wuhan is divided by natural geography and has been developed and constructed according to the polycentric model since the early stage of urban development. Additionally, the number of parks and squares did not have a significant effect on the travel distance of the elderly, most likely because, since Wuhan proposed building a garden city in 1998, the city has spent more than twenty years in achieving the goals of being able to reach community greenways in 5–10 min, urban greenways in 15–20 min, and urban greenways in 30–45 min. As a result, most elderly people in urban areas can reach a park by walking.

Table 7. Regression results of significant variables affecting travel distance for the elderly.

	Non-Standardized Coefficient		Standard Coefficient	70.37.1		6::
Variable	В	Standard Error		I-Value	<i>p</i> -value	Significance
Intercept	21,194.236	2467.437		8.590	< 0.001	***
Distance from the sub city center	986.065	79.158	0.728	12.457	< 0.001	***
Station opening time	-30.541	4.768	-0.243	-6.406	< 0.001	***
Betweenness centrality	-39,664.354	5673.015	-0.477	-6.992	< 0.001	***
Building Floor area ratio	4816.496	729.319	0.414	6.604	<0.001	***
$N_{-1-} *** = < 0.01$						

**Note**: \*\*\*  $p \le 0.01$ .

Similarly, by using OLS and GWR to build the regression model, it can be seen in Table 8 that the simulation result of GWR was better than that of OLS. The effects of the above factors on the travel distance of metros for the elderly were also visualized.

Table 8. Comparison of fitting results between the OLS model and the GWR model.

Model	Residual Sum of Squares	Coefficient of Determination	Adjusted Coefficient of Determination	AICc
OLS	4,663,807,413.5320	0.0832	0.0495	2873.2332
GWR	1,477,237,421.1811	0.7096	0.6050	2773.4024

(1) The distance of stations from urban subcenters has a significant positive effect on the distance of metro trips for the elderly in general, which is consistent with most existing studies [13,14]. This is because in polycentric cities, urban subcenters have abundant public service facilities and a large number of jobs, making them important destinations for residents. Therefore, the further the distance from the subcenter, the longer the travel distance. From Figure 6a, we can see that the positive effect of subway travel distance for the elderly is most significant outside the Second Ring Road of Hankou, in the southern part of Wuchang, and in Hanyang. This is because Wuhan is a typical polycentric city due to its natural geographical barrier. The subcenter in the riverside area of Hankou and the subcenter in the central part of Wuchang are the two best-developed subcenters in Wuhan, and the Wangjiadun subcenter in the central part of Hanyang is a key subcenter developed in recent years. Therefore, the more distant the area is from the above subcenters, the longer

the average subway travel distance for the elderly. Conversely, there is a shorter average subway travel distance for the elderly in the areas near the subcenters.

(2) In terms of station opening time, Lines 1, 2, and 4 were mainly connected to the core area of Wuhan, among which Line 1 is mainly connected to the Hankou riverside area, Line 2 is connected to the core business area of Hankou and Wuchang, and Line 4 is connected to the Wuhan and Wuchang railway stations. With the opening of Line 4, Wuhan's metro line network formed. Since Lines 1, 2, and 4 connect the four subcenters of Hankou, Xudong, Zhongnan-Hanjie, and Guanggu, the elderly can travel to the subcenters nearby. Subsequently, metro lines were opened, and a circular radial line network layout was formed, where the Line 2 extension, Line 11, and other line networks were connected to the distant urban areas of Wuhan, so the elderly in these regional stations traveled a relatively long distance.



**Figure 6.** Spatial variation in the impact of different built environment elements on metro travel distance for the elderly.

(3) Betweenness centrality has a negative impact on the distance traveled by elderly people on metros. Betweenness centrality measures the extent to which the metro station is in the "middle" of other stations, reflecting the importance of the station in the rail network. The higher the betweenness centrality, the more paths the station can connect with other stations, i.e., the better the accessibility of the network. Among the three areas of Wuhan, the betweenness centrality of Hankou was the highest, followed by Wuchang, and Hanyang was the smallest. Thus, it was found that betweenness centrality had a significant negative effect on the travel distance in Hankou, between positive and negative in the

Wuchang area, and a positive effect in Hanyang. This indicated that the circulation of the metro network helps to reduce the distance of metro travel for the elderly. This was consistent with the findings of Peng et al. [53].

(4) The overall significant positive effect of building floor area ratio and travel distance for the elderly is inconsistent with most existing studies but is consistent with the results of Yan et al.'s study based on Wuhan commuters [56]. However, further analysis reveals that the reasons for this phenomenon may be different from those of Yan et al. The reason for the results in Yan et al.'s study based on commuters is the influence of the natural pattern and history of Wuhan [56], which makes many long-distance commutes across the river in high building floor area ratio areas within the Third Ring Road. Through Figure 6d we can see that the areas with long-distance metro trips for elderly people in Wuhan are mainly located outside the Third Ring Road. This is because urban centers and subcenters have always dominated public services and employment, while the construction of public service facilities and leisure and recreation facilities in suburban areas outside the Third Ring Road has lagged, resulting in the concentration of elderly people's travel destinations in urban centers and subcenters. This, in turn, leads to longer distances for metro travel. On the contrary, in the core area of Hankou within the Second Ring Road, as the public service facilities in this area are more complete, and the effect of building floor area ratio on the travel distance is consistent with most existing studies, the higher the floor area ratio, the shorter the subway travel distance. This indicates that the effect of building floor area ratio on the travel distance of residents is significantly related to the availability of public services in the area [56,57].

# 5. Conclusions

This study examined the relationship between the built environment of metro stations and elderly metro travel characteristics. In the context of global aging, the elderly population will increase significantly in the coming decades [4,8]. With the improvement of living standards and the extension of life expectancy, the willingness of elderly people to travel is stronger than ever, and the construction of a metro system that is compatible with the travel needs of the elderly is an important manifestation of sustainable social development and transportation equity [4,29,58]. Especially in high-density development-oriented countries, an age-friendly metro system has a positive effect on improving the mobility of the elderly. However, in this study, the existing metro's age friendliness was mostly reflected in the standardized configuration of transportation concessions and accessibility facilities and was not considered from the humanistic perspective of how the built environment was friendly to the elderly's metro travel. In this study, based on smart-card data, the characteristics of elderly people's metro travel was explored objectively. A GWR model was established to analyze the influential built environment elements that affect elderly people's metro ridership and travel distance, and the research results can provide an important reference for constructing age-friendly metros.

In terms of the effect of the built environment on the elderly's metro ridership, the building volume ratio and the number of commercial facilities in the station area have a significant positive effect. This further confirms the findings of previous studies that compacted development around metro stations helps to increase metro traffic and that improving commercial facilities around metro stations is particularly important for the elderly's metro ridership [13,47]. The spatial heterogeneity of road intersections in the central city and suburban areas suggests that improving the accessibility and safety of elderly people walking to metro stations has an important impact on promoting elderly people's choice of metro travel. In addition, the ridership of elderly passengers at transfer stations is significantly higher than that at non-transfer stations, and a focus on optimizing the built environment of transfer stations may be more conducive to promoting rail travel among the elderly. One point worth noting is that the number of park squares does not have a significant effect on the elderly's travel flow, probably because the coverage of park squares in Wuhan is high and the elderly can reach neighboring park squares by

walking; however, this does not mean that park squares do not have a significant effect on the elderly's participation in activities.

In terms of the effect of the built environment on the distance of the metro for the elderly, the distance of the station from the subcenter has a positive effect on the distance of the metro for the elderly, indicating that the polycentric urban development pattern helps to reduce the distance of the metro for the elderly. The differential impact of station opening time and building volume ratio on the travel distance of the elderly in different areas is due to the different public service facilities in different districts. Therefore, improving the public service facilities in each district can help to reduce the travel distance of the elderly. The difference in betweenness centrality among the three areas of Wuhan suggests that improving the connectivity of the metro network will help to reduce the travel distance of the elderly. Similarly, transfer stations have a significant effect on the travel distance of the elderly. In addition, the travel distance of elderly people at the first and last stations is significantly higher than that at the sub first and last stations, which is due to the fact that the first and last stations are generally located in areas far from the city center, where the efficiency and reliability of the metro has obvious advantages compared to other transportation modes, but the travel distance is longer due to the station location characteristics. Therefore, in urban planning, planners should value the elderly population living at the ends of metro lines and focus on the relevant public service facilities in order to avoid the elderly's long-distance travel.

This study had certain limitations and is worthy of further study. First, the crosssectional data used in this study can only provide evidence for the association between variables and cannot derive causal relationships. In the future, we encourage the use of more dynamic time series and multisource big data. Second, the socioeconomic attribute characteristics of the elderly and the comfort of metro ridership both have an impact on the travel patterns of the elderly. A questionnaire should be added in future research to investigate this. Third, the data used in this study were before the current pandemic. As they are the group most severely affected by pandemics, the elderly will verify the influence of the built environment on the travel of metros in the background of epidemic normalization, providing more beneficial views for the construction of age-friendly metros in the post-pandemic era. In addition, in daily life, elderly people may connect to metro stations from different influence ranges, which means that the metro ridership of the elderly may come from outside the influence range set in this paper. Therefore, in the next research study, we will consider setting multiple circles of the influence range and further compare the influence of different spatial ranges of the built environment on ridership through multiscale geographically weighted regression.

Author Contributions: Conceptualization, Hong Yang, Jiandong Peng and Zehan Ruan; methodology, Hong Yang, Jiandong Peng and Wenshu Li; formal analysis, Hong Yang and Zehan Ruan; validation, Huanjie Zhu; investigation, Hong Yang and Jie Zhao; writing—original draft preparation, Hong Yang and Zehan Ruan; writing—review and editing, Wenshu Li, Huanjie Zhu and Jiandong Peng All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

**Data Availability Statement:** Some data used during the study are confidential and may only be provided with restrictions.

Conflicts of Interest: The authors declare no conflict of interest.

### References

- 1. Nations, U.; Economic, D.; Affairs, S.; Division, P. World Population Prospects 2019 Highlights; United Nations: New York, NY, USA, 2019.
- Cao, X.; Mokhtarian, P.L.; Handy, S.L. Neighborhood Design and the Accessibility of the Elderly: An Empirical Analysis in Northern California. *Int. J. Sustain. Transp.* 2010, 4, 347–371. [CrossRef]
- Cheng, L.; Chen, X.; Yang, S.; Cao, Z.; de Vos, J.; Witlox, F. Active Travel for Active Ageing in China: The Role of Built Environment. J. Transp. Geogr. 2019, 76, 142–152. [CrossRef]
- Yang, L. Modeling the Mobility Choices of Older People in a Transit-Oriented City: Policy Insights. *Habitat Int.* 2018, 76, 10–18. [CrossRef]
- Spinney, J.E.L.; Scott, D.M.; Newbold, K.B. Transport Mobility Benefits and Quality of Life: A Time-Use Perspective of Elderly Canadians. *Transp. Policy* 2009, 16, 1–11. [CrossRef]
- Wong, R.C.P.; Szeto, W.Y.; Yang, L.; Li, Y.C.; Wong, S.C. Public Transport Policy Measures for Improving Elderly Mobility. *Transp.* Policy 2018, 63, 73–79. [CrossRef]
- 7. Banister, D.; Bowling, A. Quality of Life for the Elderly: The Transport Dimension. Transp. Policy 2004, 11, 105–115. [CrossRef]
- Shao, F.; Sui, Y.; Yu, X.; Sun, R. Spatio-Temporal Travel Patterns of Elderly People—A Comparative Study Based on Buses Usage in Qingdao, China. J. Transp. Geogr. 2019, 76, 178–190. [CrossRef]
- Ding, C.; Cao, X.; Liu, C. How Does the Station-Area Built Environment Influence Metrorail Ridership? Using Gradient Boosting Decision Trees to Identify Non-Linear Thresholds. J. Transp. Geogr. 2019, 77, 70–78. [CrossRef]
- Gan, Z.; Yang, M.; Feng, T.; Timmermans, H.J.P. Examining the Relationship between Built Environment and Metro Ridership at Station-to-Station Level. *Transp. Res. Part D Transp. Environ.* 2020, *82*, 102332. [CrossRef]
- 11. An, D.; Tong, X.; Liu, K.; Chan, E.H.W. Understanding the Impact of Built Environment on Metro Ridership Using Open Source in Shanghai. *Cities* **2019**, *93*, 177–187. [CrossRef]
- 12. Ewing, R.; Cervero, R. Travel and the Built Environment. J. Am. Plan. Assoc. 2010, 76, 265–294. [CrossRef]
- 13. Shao, Q.; Zhang, W.; Cao, X.; Yang, J.; Yin, J. Threshold and Moderating Effects of Land Use on Metro Ridership in Shenzhen: Implications for TOD Planning. *J. Transp. Geogr.* **2020**, *89*, 102878. [CrossRef]
- 14. Zhao, P. The Impact of the Built Environment on Individual Workers' Commuting Behavior in Beijing. *Int. J. Sustain. Transp.* 2013, 7, 389–415. [CrossRef]
- 15. Kemperman, A.; Timmerman, H. Influences of Built Environment on Walking and Cycling by Latent Segments of Aging Population. *Transp. Res. Rec.* 2009, 2134, 1–9. [CrossRef]
- 16. Kuby, M.; Barranda, A.; Upchurch, C. Factors Influencing Light-Rail Station Boardings in the United States. *Transp. Res. Part A Policy Pract.* 2004, *38*, 223–247. [CrossRef]
- 17. Böcker, L.; van Amen, P.; Helbich, M. Elderly Travel Frequencies and Transport Mode Choices in Greater Rotterdam, The Netherlands. *Transportation* **2017**, *44*, 831–852. [CrossRef]
- 18. Bezirgani, A.; Lachapelle, U. Online Grocery Shopping for the Elderly in Quebec, Canada: The Role of Mobility Impediments and Past Online Shopping Experience. *Travel Behav. Soc.* **2021**, *25*, 133–143. [CrossRef]
- 19. Feng, J.; Dijst, M.; Wissink, B.; Prillwitz, J. Elderly Co-Residence and the Household Responsibilities Hypothesis: Evidence from Nanjing, China. *Urban Geogr.* **2015**, *36*, 757–776. [CrossRef]
- Hu, X.; Wang, J.; Wang, L. Understanding the Travel Behavior of Elderly People in the Developing Country: A Case Study of Changchun, China. Procedia Soc. Behav. Sci. 2013, 96, 873–880. [CrossRef]
- Moniruzzaman, M.; Páez, A. An Investigation of the Attributes of Walkable Environments from the Perspective of Seniors in Montreal. J. Transp. Geogr. 2016, 51, 85–96. [CrossRef]
- 22. Sun, B.; Ermagun, A.; Dan, B. Built Environmental Impacts on Commuting Mode Choice and Distance: Evidence from Shanghai. *Transp. Res. Part D Transp. Environ.* 2017, 52, 441–453. [CrossRef]
- 23. Zhang, M. The Role of Land Use in Travel Mode Choice: Evidence from Boston and Hong Kong. J. Am. Plan. Assoc. 2004, 70, 344–360. [CrossRef]
- Borst, H.C.; de Vries, S.I.; Graham, J.M.A.; van Dongen, J.E.F.; Bakker, I.; Miedema, H.M.E. Influence of Environmental Street Characteristics on Walking Route Choice of Elderly People. J. Environ. Psychol. 2009, 29, 477–484. [CrossRef]
- El-Geneidy, A.; Grimsrud, M.; Wasfi, R.; Tétreault, P.; Surprenant-Legault, J. New Evidence on Walking Distances to Transit Stops: Identifying Redundancies and Gaps Using Variable Service Areas. *Transportation* 2014, 41, 193–210. [CrossRef]
- Moniruzzaman, M.; Paez, A.; Scott, D.; Morency, C. Trip Generation of Seniors and the Geography of Walking in Montreal. Environ. Plan. A Econ. Space 2015, 47, 957–976. [CrossRef]
- Jun, M.J.; Choi, K.; Jeong, J.E.; Kwon, K.H.; Kim, H.J. Land Use Characteristics of Subway Catchment Areas and Their Influence on Subway Ridership in Seoul. J. Transp. Geogr. 2015, 48, 30–40. [CrossRef]
- Cheng, L.; Caset, F.; de Vos, J.; Derudder, B.; Witlox, F. Investigating Walking Accessibility to Recreational Amenities for Elderly People in Nanjing, China. *Transp. Res. Part D Transp. Environ.* 2019, 76, 85–99. [CrossRef]
- 29. Chudyk, A.M.; Winters, M.; Moniruzzaman, M.; Ashe, M.C.; Gould, J.S.; McKay, H. Destinations Matter: The Association between Where Older Adults Live and Their Travel Behavior. *J. Transp. Health* **2015**, *2*, 50–57. [CrossRef]
- Loukaitou-Sideris, A.; Levy-Storms, L.; Chen, L.; Brozen, M. Parks for an Aging Population: Needs and Preferences of Low-Income Seniors in Los Angeles. J. Am. Plan. Assoc. 2016, 82, 236–251. [CrossRef]

- 31. Van den Berg, A.E.; Maas, J.; Verheij, R.A.; Groenewegen, P.P. Green Space as a Buffer between Stressful Life Events and Health. *Soc. Sci. Med.* **2010**, *70*, 1203–1210. [CrossRef]
- Lin, T.; Xia, J.; Robinson, T.P.; Goulias, K.G.; Church, R.L.; Olaru, D.; Tapin, J.; Han, R. Spatial Analysis of Access to and Accessibility Surrounding Train Stations: A Case Study of Accessibility for the Elderly in Perth, Western Australia. *J. Transp. Geogr.* 2014, 39, 111–120. [CrossRef]
- Truong, L.T.; Somenahalli, S.V.C. Exploring Frequency of Public Transport Use among Older Adults: A Study in Adelaide, Australia. *Travel Behav. Soc.* 2015, 2, 148–155. [CrossRef]
- Wong, R.C.P.; Szeto, W.Y.; Yang, L.; Li, Y.C.; Wong, S.C. Elderly Users' Level of Satisfaction with Public Transport Services in a High-Density and Transit-Oriented City. J. Transp. Health 2017, 7, 209–217. [CrossRef]
- 35. Sung, H.; Choi, K.; Lee, S.; Cheon, S.H. Exploring the Impacts of Land Use by Service Coverage and Station-Level Accessibility on Rail Transit Ridership. *J. Transp. Geogr.* **2014**, *36*, 134–140. [CrossRef]
- Hallgrimsdottir, B.; Svensson, H.; Ståhl, A. Long Term Effects of an Intervention in the Outdoor Environment-a Comparison of Older People's Perception in Two Residential Areas, in One of Which Accessibility Improvements Were Introduced. J. Transp. Geogr. 2015, 42, 90–97. [CrossRef]
- 37. Hess, D.B. Access to Public Transit and Its Influence on Ridership for Older Adults in Two U.S. Cities; University at Buffalo: New York, NY, USA, 2009; Volume 2.
- Sun, G.; Lau, C.Y. Go-along with Older People to Public Transport in High-Density Cities: Understanding the Concerns and Walking Barriers through Their Lens. J. Transp. Health 2021, 21, 101072. [CrossRef]
- 39. Guo, J.Y.; Chen, C. The Built Environment and Travel Behavior: Making the Connection. *Transportation* **2007**, *34*, 529–533. [CrossRef]
- 40. Broome, K.; Worrall, L.; Fleming, J.; Boldy, D. Evaluation of Flexible Route Bus Transport for Older People. *Transp. Policy* 2012, 21, 85–91. [CrossRef]
- 41. Zhang, Y.; Yao, E.; Zhang, R.; Xu, H. Analysis of Elderly People's Travel Behaviours during the Morning Peak Hours in the Context of the Free Bus Programme in Beijing, China. *J. Transp. Geogr.* **2019**, *76*, 191–199. [CrossRef]
- 42. Bivina, G.R.; Gupta, A.; Parida, M. Walk Accessibility to Metro Stations: An Analysis Based on Meso- or Micro-Scale Built Environment Factors. *Sustain. Cities Soc.* 2020, *55*, 102047. [CrossRef]
- 43. Gao, Y.; Zhao, J.; Han, L. Exploring the Spatial Heterogeneity of Urban Heat Island Effect and Its Relationship to Block Morphology with the Geographically Weighted Regression Model. *Sustain. Cities Soc.* **2022**, *76*, 103431. [CrossRef]
- Collia, D.V.; Sharp, J.; Giesbrecht, L. The 2001 National Household Travel Survey: A Look into the Travel Patterns of Older Americans. J. Saf. Res. 2003, 34, 461–470. [CrossRef] [PubMed]
- 45. Szeto, W.Y.; Yang, L.; Wong, R.C.P.; Li, Y.C.; Wong, S.C. Spatio-Temporal Travel Characteristics of the Elderly in an Ageing Society. *Travel Behav. Soc.* **2017**, *9*, 10–20. [CrossRef]
- Sohn, K.; Shim, H. Factors Generating Boardings at Metro Stations in the Seoul Metropolitan Area. *Cities* 2010, 27, 358–368. [CrossRef]
- Su, S.; Zhao, C.; Zhou, H.; Li, B.; Kang, M. Unraveling the Relative Contribution of TOD Structural Factors to Metro Ridership: A Novel Localized Modeling Approach with Implications on Spatial Planning. J. Transp. Geogr. 2022, 100, 103308. [CrossRef]
- Huang, X.; Cao, X.J.; Cao, X.; Yin, J. How Does the Propensity of Living near Rail Transit Moderate the Influence of Rail Transit on Transit Trip Frequency in Xi'an? J. Transp. Geogr. 2016, 54, 194–204. [CrossRef]
- 49. Ewing, R.; Hamidi, S.; Gallivan, F.; Nelson, A.; Grace, J. Combined Effects of Compact Development, Transportation Investments, and Road User Pricing on Vehicle Miles Traveled in Urbanized Areas. *Transp. Res. Rec.* **2013**, 2397, 117–124. [CrossRef]
- 50. Durning, M.; Townsend, C. Direct Ridership Model of Rail Rapid Transit Systems in Canada. *Transp. Res. Rec.* 2015, 2537, 96–102. [CrossRef]
- Gan, Z.; Yang, M.; Feng, T.; Timmermans, H. Understanding Urban Mobility Patterns from a Spatiotemporal Perspective: Daily Ridership Profiles of Metro Stations. *Transportation* 2020, 47, 315–336. [CrossRef]
- 52. Liu, Q.; Liu, Y.; Zhang, C.; An, Z.; Zhao, P. Elderly Mobility during the COVID-19 Pandemic: A Qualitative Exploration in Kunming, China. J. Transp. Geogr. 2021, 96, 103176. [CrossRef]
- 53. Peng, J.; Cui, C.; Qi, J.; Ruan, Z.; Dai, Q.; Yang, H. The Evolvement of Rail Transit Network Structure and Impact on Travel Characteristics: A Case Study of Wuhan. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 789. [CrossRef]
- Park, K.; Chamberlain, B.; Song, Z.; Nasr Esfahani, H.; Sheen, J.; Larsen, T.; Long Novack, V.; Licon, C.; Christensen, K. A Double Jeopardy: COVID-19 Impacts on the Travel Behavior and Community Living of People with Disabilities. *Transp. Res. Part A Policy Pract.* 2022, 156, 24–35. [CrossRef] [PubMed]
- Ding, C.; Cao, X.; Yu, B.; Ju, Y. Non-Linear Associations between Zonal Built Environment Attributes and Transit Commuting Mode Choice Accounting for Spatial Heterogeneity. *Transp. Res. Part A Policy Pract.* 2021, 148, 22–35. [CrossRef]
- 56. Yan, X.; Zhou, J.; Sheng, F.; Niu, Q. Influences of Built Environment at Residential and Work Locations on Commuting Distance: Evidence from Wuhan, China. *ISPRS Int. J. Geo-Inf.* **2022**, *11*, 124. [CrossRef]
- 57. Cervero, R. Built Environments and Mode Choice: Toward a Normative Framework. *Transp. Res. Part D Transp. Environ.* 2002, 7, 265–284. [CrossRef]
- Newbold, K.B.; Scott, D.M.; Spinney, J.E.L.; Kanaroglou, P.; Páez, A. Travel Behavior within Canada's Older Population: A Cohort Analysis. J. Transp. Geogr. 2005, 13, 340–351. [CrossRef]