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Transit-oriented development for older people: Does using multiple public transport options improve their physical and mental health?

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Abstract: Transit-oriented cities often use urban rail transit (e.g., metro) to lead public transport development (TOD), which might overlook other public transport options (e.g., bus) that matter for the health and wellbeing of older people. We investigate older people's public transport use patterns and how multiple public transport options are related to the physical and mental health of older people.

In the case city of Hong Kong, which is well-known for its metro-led transit-oriented development, we collected questionnaire data from 826 older people on their public transport use behaviors, route environment to normally used stops/stations, and physical and mental health. We used univariate analysis to measure explanatory factors ($P<0.25$). We applied multivariable linear regression models with several sensitivity analyses to test the associations among public transport use, route environment, and health outcomes, adjusting for covariates of individual factors, physical activity, and self-reported chronic disease.

We found that (1) using multiple public transport options was positively associated with better physical health ($p<0.001$); (2) mixed metro and bus users had the highest physical activity (high level with MET-mins/week>3,000, 75%) as well as the best physical health (physical component summary (PCS) >50, 41.42%) and mental health (mental component summary (MCS) > 50, 68.28%), compared to bus-only or metro-only users; and (3) for mixed-mode users, pedestrian crowdedness was negatively associated with physical health ($p < 0.01$), while satisfaction in sidewalk width was positively related to mental health ($p=0.038$).

We found that older people prefer multiple public transport options rather than the metro-dominated single-mode, and this travel preference benefits the physical and mental health of this population. Our research helps deepen the understanding of public transport use and associated health outcomes among older people and has policy implications for TOD planning concerning the aging population.

Keywords: Older people, metro, route environment, mental health, high-density city, Hong Kong

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1 Introduction

The rapid growth of the aging population poses a great challenge for offering travel options that consider older people's mobility needs (Musselwhite et al., 2015). Older people have different travel patterns from other age groups as the aging process is accompanied by changes in daily activities due to retirement, income reduction, and physical limitations (Kendrick et al., 2015; Ryan & Wretstrand, 2019; Shrestha et al., 2017). As people get older, they prefer public transport over driving cars (Böcker et al., 2017; Cui et al., 2017; Shrestha et al., 2017; Simons et al., 2013; Sundling et al., 2016). Understanding the travel patterns of older people is crucial in developing and implementing measures to fulfil their mobility needs, which in turn increases their social inclusion, health, wellbeing, and quality of life (Avila-Palencia et al., 2018; He et al., 2020; Mackett & Thoreau, 2015; Satariano et al., 2012).

One way to tackle the aging population's travel challenge is transit-oriented development (TOD), which refers to the practice of developing areas around transit stations into higher density, mixed land-use neighborhoods and walking-friendly street environments (Pan et al., 2017). Compared to car-dominant cities, TOD cities can fulfil the travel requirements of older people by providing a better-organized public transport network, with accessible, frequent and reliable public transport services (Wong et al., 2018). Older people can reach destinations outside their neighborhoods easily and independently, thus more likely to stay mobile and maintain physical and mental health. However, TOD is usually not designed to meet the specific needs of older people but to encourage its use by the general population (Duncan et al., 2021). Most TOD planning often ignores the complex travel requirements of older people.

There are mismatches between TOD designs and the needs of older people. One is that TOD cities rely on the metro as the public transport system's backbone and adjust bus lines to be metro stations' feeder rides. With a continued expansion of the metro system, such as in Hong Kong, there are cancellations, truncations, and reductions of existing bus services. Previous studies showed that bus trips take up the highest proportion of daily trips made by older people in the metro-led TODs in high-density cities (Szeto et al., 2017). Little research has been focused on the mismatch between the provision of public transport services and the demand of older people, and how this might be associated with their behavior and health outcomes. Another mismatch is that TOD often assumes that the criteria for pedestrian-friendly environments are the same for everyone. However, older people might have a different perception (Duncan et al., 2021). The high-density mixture of land use in TOD areas' development brings accessibility benefits. Still, it may also bring difficulties to older people by sidewalk barriers, pedestrian crowdedness, and insufficient rest areas along the way to the stations (Simons et al., 2013; Wong et al., 2017). Few studies have explored the role of route environment for different public transport modes and how it may affect the relationship between public transport use and health outcomes for older people.

In this study, we investigate the public transport use patterns of older people and how the use of multiple public transport modes is related to their physical and mental health to understand the mismatches between TOD and the needs of older people and their impacts (See Figure 1). We hypothesize that mixed-mode use of public transport can lead to better physical and mental health. The route environment characteristics can change the above associations. Our study area is Hong Kong, with a reputable metro-led transit-oriented development and a rapidly aging population. We aim to understand how vital it could be to maintain public bus services in a metro-led city by answering the following questions:

1. How do multiple public transport options associate with their physical and mental health?
2. How do route environments for public transport use change the above relationships?

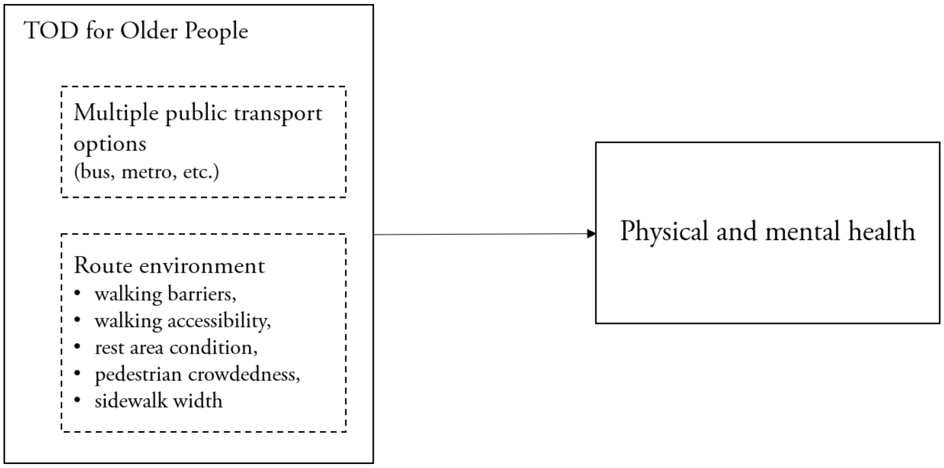

Figure 1. Conceptual model

2 Literature review

2.1 TOD and travel behavior of older people

TOD is a sustainable urban planning strategy for reducing car reliance and promoting transit use for people of all ages (He et al., 2018; Kamruzzaman et al., 2015; Langlois et al., 2016; Pan et al., 2017). Cities with TOD usually have well-organized urban rail transit networks (Zhu et al., 2020). Older people living in these TOD cities rely less on car use and make more daily trips (Duncan et al., 2021). A study in the United States found older people living in TOD neighborhoods substantially decreased car use, with a 61% increase in non-car trips than those living in non-TOD neighborhoods (Boschmann & Brady, 2013). In Hong Kong, older people are highly dependent on public transport for travelling (Szeto et al., 2017; Wong et al., 2018). People make over 90% of their daily trips via the metro and public buses (Transport Department, 2014).

However, older people's specific needs and preferences are not considered in the design and implementation of TODs (Duncan et al., 2021). TOD is simply treated as a method for generating metro ridership in many contexts (He et al., 2018; Kamruzzaman et al., 2015; Xue & Sun, 2018). It assumes that people living in transit-oriented neighborhoods usually use the metro for travelling, but overlooks older people's travel patterns and preferences (Kamruzzaman et al., 2015). Previous research demonstrated that older adults prefer to use public buses rather than the metro (Szeto et al., 2017). The main reason is that, in contrast to accessing bus services, accessing metro services requires more physical effort, such as having to walk through extensive underground networks with level connectors linked with metro stations (Sun et al., 2019). Bus lines have been gradually reduced, adjusted, or cancelled with the expansion of the metro systems in metro-led and transit-oriented cities such as Hong Kong. The restriction of bus services might reduce public transport use among older adults, thus impacting their health.

Little is known about how travel preferences and requirements may affect physical and mental health and how TOD can be better planned by providing multiple public transport options for older people. Previous studies assumed public transport to be one undifferentiated mode, ignoring the heterogeneity of multiple modes under the public transport category. They have not compared the health effects of single and multiple public transport options, which is a more realistic concern on the public transport use of older people in TOD cities.

2.2 Public transport use and health

Numerous studies have shown evidence that public transport use can bring health benefits to the aging population (Avila-Palencia et al., 2018; He et al., 2020; Laverty et al., 2018; Mackett, 2017; Musselwhite et al., 2015; Reinhard et al., 2018; Ryan & Wretstrand, 2019).

Public transport use can impact physical health through several pathways. First, there is always a need to walk when using public transport, including first-mile and last-mile trips and making transfers during the journey (Sun et al., 2017). The additional walking can help achieve the World Health Organization's (WHO) recommended physical activity level for older people (Rissel et al., 2012), thus reducing the risk of obesity, cancer, cardiovascular disease, and other chronic diseases (Cerin et al., 2016; Forsyth et al., 2009; Mackett & Thoreau, 2015; Nieuwenhuijsen et al., 2016; Stefansdottir et al., 2019). Second, public transport use can decrease the mortality rate associated with vehicle collisions (Green et al., 2016). Moreover, public transport use can also reduce air pollution and urban heat island effects, which may cause physical health problems such as lung disease (Khreis et al., 2016; Nieuwenhuijsen et al., 2017).

Public transport use can also influence mental health and wellbeing among older people (Ettema et al., 2010; Friman et al., 2018; Friman & Olsson, 2020; McCarthy & Habib, 2018; Mokhtarian, 2019). First, public transport use can link to mental health by directly affecting older people's moods and feelings during travel. The travelling itself could be relaxing and refreshing, which increases energy and improves mood. Previous studies found that regular physical activity associated with public transport use can reduce stress and anxiety among older people (Paluska & Schwenk, 2000; Windle et al., 2010). Moreover, public transport use can benefit mental health by enabling activities that satisfy the basic or social needs of older people (Du et al., 2022). This helps prevent depression caused by social exclusion (Reinhard et al., 2018). Improving public transport services could thus enhance older people's mental health (Mackett, 2017).

2.3 The role of the route environment

A walking-friendly route environment would support mobility and thus affect older people's physical and mental health. The travel willingness of older people is related to built-environment characteristics such as density, street connectivity, overall access to destinations and services, and quality of walking facilities and infrastructure (Barnett et al., 2017). The proximity to a stop/station is one of the most important predictors of whether older people would make a trip or not. A survey in Hong Kong found that older people were less willing to walk more than 12 minutes to access public transport (Transport Department, 2014). Physical barriers such as slopes, obstacles, and curb height might decrease public transport use due to age-related physical constraints (Moran et al., 2014; Van Cauwenberg et al., 2011). Narrow sidewalks and the associated pedestrian crowdedness have become a growing concern in high-density cities. Worries about bumping or falling can lead to a decline in public transport use among older adults (Jiao et al., 2017; Li & Hensher, 2013; Loo & Lam, 2012; Van Holle et al., 2012; Yen et al., 2014). Rest areas (e.g., available seats) at bus stops or metro stations also determine the mode choice for older people (Wong et al., 2018). Previous studies show that a lack of seating and insufficient sidewalk width might reduce older Hong Kong residents' willingness to make a trip (Lau, 2019).

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[1] A 750m buffer effectively covers the majority of the upper east side area and the adjacent existing metro line. Additionally, it excludes the properties directly located at the edge of the Central Park, which can maintain price premium from the view to the park that we have no variables to control for.

3 Methods

3.1 Study design

The study city of Hong Kong is one of the most densely populated places in the world. Over 7 million people live within its area of 1,068 square kilometers, but more than 75% of the land is non-built-up area (Census and Statistics Department, 2020). It is a well-known TOD city (Shelton et al., 2011). Walking in the city is shaped by over 800 footbridges and 60 km of pedestrian undergrounds that connected with metro stations (Sun et al., 2015; Sun et al., 2019). Over 90% of the daily trips in the city are made by public transport, mainly the metro and public buses (Transport Department, 2014). Public transport focuses on metro development to sustain the high-density built environment. The metro has expanded from 212 km and 84 stations in 2007 to over 270 km and 98 stations by 2019 (Sun et al., 2021), and the government plans to double its size. The public bus has been reduced or adjusted along with the metro expansion.

This research is part of the Metro and Elderly Health in Hong Kong Study, a natural experiment to investigate the before and after effects of a new metro line on public transport use, physical activity and wider health outcomes of older people. A study protocol paper was published elsewhere (Sun et al., 2021). For this paper, we report the baseline data consisting of 826 participants aged 65 or above, living within 400 meters pedestrian-network buffers of 9 metro stations across Hong Kong, and able to walk unassisted for at least 15 minutes. The 9 study sites consisted of metro and non-metro areas (See Figure 2). Metro areas referred to the study sites where metro stations had been in operation, while non-metro areas included those sites with stations that had been built but were not yet open in the baseline survey. Participants were recruited through neighborhood elderly centers in the study sites (Sun et al., 2021). Note that in Hong Kong, 170 neighborhood elderly centers cover the territory to provide the Government's community services for older people at the neighborhood level, and elderly center-based recruitment can guarantee a retention rate for follow-up surveys (Cerin et al., 2016).

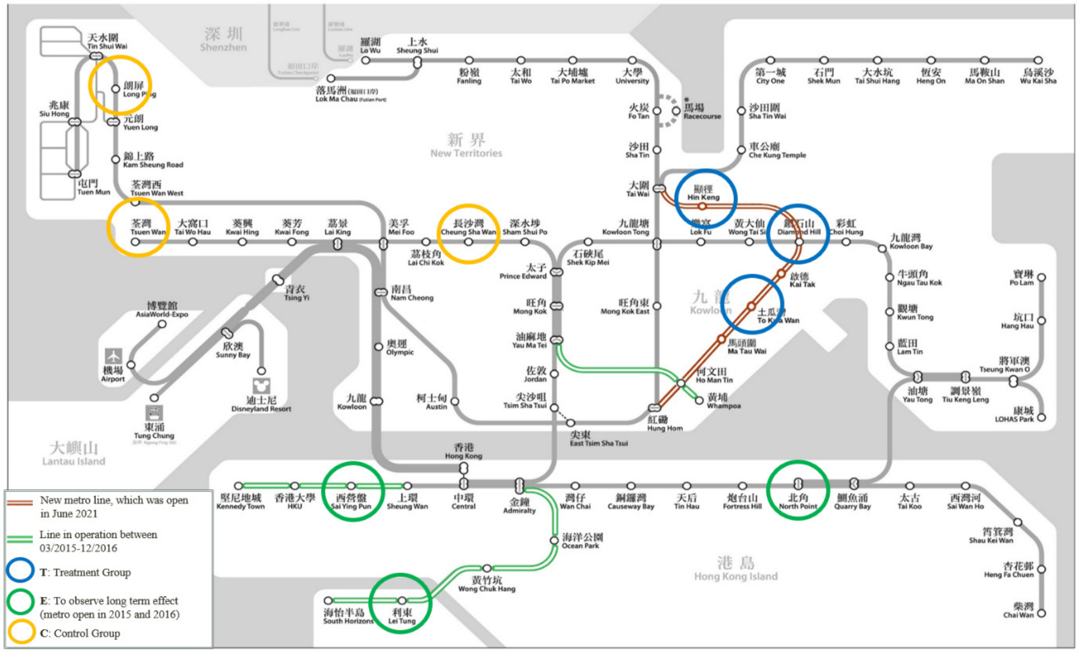

Figure 2. Study sites

Participants answered questions of validated 12-item Short-Form Health Survey (SF-12) (Lam et al., 2005), public transport mode choice and route environment assessment, International Physical Activity Questionnaire for Chinese Seniors (IPAQ-C) (Cerin et al., 2012), self-reported chronic diseases and their mobility impact, and individual factors. Table 1 shows the variable descriptions, response scales and coding.

The baseline data were collected in 2019. The survey was conducted in an interviewer-administered way, with each taking 40–60 minutes. Ethical approval for the study was obtained from the Research Ethics Committee of the University of Hong Kong (Reference Number: EA1710040), and written informed consent was provided by each participant.

Table 1. Questionnaire items used in the survey

Variables	Item description	Response scale and coding
Physical and mental health		
Physical component summary (PCS)	12-Item Short Form Health Survey (SF-12) (e.g., "During the past week, have you had any of the following problems with your regular daily activities as a result of your physical health?")	0-100
Mental component summary (MCS)	12-Item Short Form Health Survey (SF-12) (e.g., "During the past week, have you had any of the following problems with your regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?")	0-100
Mode choice and route environment		
Public transport mode choice	You 'always', 'sometimes' or 'never' travel by the options of the bus, minibus, and metro (Only one mode can be marked as 'always')	1. Bus use only (if participants always used the bus and/or minibus but never used the metro) 2. Metro use only (if participants always used the metro but never used the bus and/or minibus) 3. Mixed mode (participants who 'always used the bus/minibus and sometimes used the metro' and 'always used the metro and sometimes used the bus/minibus)
Walking barrier	Are there any walking barriers when you access the normally used bus stop or metro station?	No, Yes
Walking time from home to the normally used stop/station	Is the bus stop (or metro station) accessible within 10 minutes of walking from your home?	No, Yes
Rest area condition	Are you satisfied with the resting facilities at the normally used bus stop/ metro station?	1. Low, 2. Moderate, 3. High
Pedestrian crowdedness	How do you evaluate the pedestrian crowdedness of the route environment to the normally used bus stop/metro station?	1. Low, 2. Moderate, 3. High

Variables	**Item description**	**Response scale and coding**
Sidewalk width satisfaction	Are you satisfied with the sidewalk width of the route environment to the normally used bus stop/metro station?	1. Low, 2. Moderate, 3. High
Physical activity, chronic disease and other individual factors		
Physical activity	IPAQ-C is used for older adults to assess physical activity (e.g., "During the last seven days, on how many days did you walk for at least 10 minutes at a time? How much time did you usually spend walking on one of those days?")	1. low (<600 MET-mins/week), 2. moderate (600–3,000 MET-mins/week with at least five days of any combination of activities), 3. high (>3,000 MET-mins/week with at least seven days of any combination of activities)
If having a chronic disease	Do you have any chronic diseases? (e.g., heart disease, lung disease, hypertension, high cholesterol, hyperglycemia, cancer, rheumatoid arthritis, stroke sequelae, dementia, respiratory diseases, and mood disorders)	No, Yes, answer the following question
Impact of chronic disease on mobility	The chronic disease you have impact your ability to make a trip.	1. Not at all, 2. A little, 3. Some, 4. A lot, 5. Extremely
Gender		1. Man, 2. Woman
Age		1. 65-69 2. 70-79 3. 80-89 4. ≥90
Monthly income		1. <2000 2. 2000-4000 3. 4001-6000 4. 6001-10000 5. >10000

3.2 Variables

3.2.1 Health outcomes

We used the validated SF-12 to assess participants' physical and mental health over the past four weeks (Lam et al., 2005). The SF-12 is a widely used, self-reported measure of health status that measures eight domains: physical functioning, physical role limitations, bodily pain, general health perceptions, energy, social functioning, emotional role limitations, and mental health. The results are two scores, the physical component score (PCS) and the mental component score (MCS), following the methods outlined by Ware et al. (Ware et al., 1995). The PCS and MCS scores each range from 0 to 100, with a higher score indicating a better health status. In this study, the PCS and MCS were assessed as continuous variables.

3.2.2 Mode choice and route environment

Participants had three public transport mode choices: bus only for participants who only used the public bus for travel, metro only for those who only used the metro, and mixed modes for those who used both metro and bus.

Route-environment features included walking barriers, walking time, rest area conditions at the normally used bus stop or metro station, pedestrian crowdedness and sidewalk width satisfaction.

3.2.3 Covariates

Our covariates included physical activity assessed by IPAQ-C, self-reported chronic diseases and their mobility impact. Gender, age and monthly income were collected as individual factors.

3.3 Statistical analysis

We conducted descriptive statistics to provide a profile of participants. Multivariable linear regression models were then used to analyze the relationships between public transport mode choice, route environment and physical and mental health.

All statistical analyses were conducted in Stata (v. 17, StataCorp).

- ***Analysis 1: Association between public transport mode choice and health outcomes***

We assessed the health impact of the public transport mode choice. The models were fitted in three steps. First, we used univariate analysis to assess the associations of mode choice and covariates on health outcomes. We only included those variables with a significance level ($p<0.25$) in later multivariable models. Secondly, we tested the associations between health outcomes and public transport mode choices, adjusting for individual factors (e.g., gender, age and monthly income). Thirdly, we added self-reported health status variables (e.g., physical activity and chronic disease) to the models.

- ***Analysis 2: Association between route environment and health outcomes***

We modelled the health impact of the route environment for each mode choice (e.g., bus, metro, mixed mode). We followed the above progressively modelling approach to include covariates. The route environment variables were included in the models according to the mode choice of participants. We separately ran models with data for bus-only, metro-only and mixed-mode groups.

- ***Analysis 3: Sensitivity tests***

We conducted sensitivity tests by assessing subgroup data from metro areas and non-metro areas. We applied the multivariable linear regression models to each subgroup to observe the stability of the models.

4 Results

4.1 Participants

Table 2 shows descriptive statistics of the study sample. Overall, we had more women (63.08%) than men, which was higher than the female ratio of people aged over 65 (53.40%) in Hong Kong (Census and Statistics Department, 2020). Of the 826 participants, 51.09% were aged 70 to 79 years; 45.52% had a monthly income between 2,000 and 4,000 HKD; 82.93% had chronic diseases, 40.29% reported chronic diseases to impact their mobility, and 68.77% had a high level of physical activity.

Among the participants, 64.89% used multiple public transport modes (bus and metro). These mixed-mode users had the highest level of physical activity and physical health among the three groups (bus-only, metro-only, and mixed-mode). The percentage of people who engaged in a high level of physical activity was highest in the mixed-mode group at 75%, compared to 60.93% and 46.67% in the bus-only and metro-only groups, respectively. Scores for physical health were highest in the mixed-mode group (mean = 46.04) compared to mean scores of 42.19 and 44.16 in the bus-only and metro-only groups, respectively. However, the metro-only users had relatively higher mental health scores (mean =

52.51) than the mixed-mode (mean = 51.92) and bus-only users (mean = 51.65), with mean scores of 51.92 and 51.65, respectively.

Table 2. Descriptive statistics of the participants

	All participants (n=826)	**Bus-only group (n=215)**	**Metro-only group (n=75)**	**Mixed-mode group (n=536)**
	Mean (SD)/ N (%)	**Mean (SD)/ N (%)**	**Mean (SD)/ N (%)**	**Mean (SD)/ N (%)**
PCS	44.87 (8.50)	42.19 (8.82)	44.16 (8.12)	46.04 (8.17)
MCS	51.91 (9.09)	51.65 (9.21)	52.51 (8.14)	51.92 (9.18)
Mode choice				
Bus use only		215 (26.03)		
Metro use only			75 (9.08)	
Mixed mode				536 (64.89)
Route environment (to bus stop)				
Walking barrier	149 (18.04)	49 (22.79)	12 (16.00)	88 (16.42)
Walking time < 10 mins	690 (83.54)	179 (83.26)	60 (80.00)	451 (84.14)
Rest area condition				
Low	180 (21.79)	60 (27.91)	22(29.33)	98(18.28)
Moderate	199 (24.09)	42 (19.53)	22 (29.33)	135 (25.19)
High	447 (54.12)	113 (52.56)	31 (41.33)	303 (56.53)
Pedestrian crowdedness				
Low	358 (43.34)	101 (46.98)	27 (36.00)	230 (42.91)
Moderate	343 (41.53)	82 (38.14)	26 (34.67)	235 (43.84)
High	125 (15.13)	32 (14.88)	22 (29.33)	71 (13.25)
Sidewalk width satisfaction				
Low	63 (7.63)	22 (10.23)	4 (5.33)	37 (6.90)
Moderate	548 (66.34)	135 (62.79)	53 (70.67)	360 (67.16)
High	215 (26.03)	58 (26.98)	18 (24.00)	139 (25.93)
Route environment (to metro station)				
Walking barrier	70 (8.47)	16 (7.44)	6 (8.00)	48 (8.96)
Walking time < 10 mins	353 (45.26)	40 (22.47)	40 (54.79)	273 (51.61)
Rest area condition				
Low	278 (33.66)	84 (39.07)	23 (30.67)	171 (31.90)
Moderate	334 (40.44)	82 (38.14)	20 (26.67)	232 (43.28)
High	214 (25.91)	49 (22.79)	32 (42.67)	133 (24.81)
Pedestrian crowdedness				
Low	192 (23.24)	42 (19.53)	18 (24.00)	132 (24.63)
Moderate	241 (29.18)	49 (22.79)	27 (36.00)	165 (30.78)
High	393 (47.58)	124 (57.67)	30 (40.00)	239 (44.59)

	All participants (n=826)	**Bus-only group (n=215)**	**Metro-only group (n=75)**	**Mixed-mode group (n=536)**
	Mean (SD)/ N (%)	**Mean (SD)/ N (%)**	**Mean (SD)/ N (%)**	**Mean (SD)/ N (%)**
Sidewalk width satisfaction				
Low	199 (24.09)	56 (26.05)	18 (24.00)	125 (23.32)
Moderate	412 (49.88)	101 (46.98)	39 (52.00)	272 (50.75)
High	215 (26.03)	58 (26.98)	24 (24.00)	139 (25.93)
Physical activity				
Low	9 (1.09)	1 (0.47)		8 (1.49)
Moderate	249 (30.15)	83 (38.60)	40 (53.33)	126 (23.51)
High	568 (68.77)	131 (60.93)	35 (46.67)	402 (75.00)
Have chronic disease	685 (82.93)	186 (86.51)	60 (80.00)	439 (81.90)
Perceived mobility impacts	1.76 (1.08)	1.90 (1.19)	1.80 (1.16)	1.71 (1.02)
Female	521 (63.08)	137 (63.72)	51 (68.00)	333 (62.13)
Age				
65-69	149 (18.04)	35 (16.28)	11 (14.67)	103 (19.22)
70-79	422 (51.09)	87 (56.74)	39 (52.00)	296 (55.22)
80-89	223 (27.00)	79 (36.74)	25 (33.33)	119 (22.20)
≥ 90	32 (3.87)	14 (6.51)		18 (3.36)
Monthly income (HKD)				
< 2000	83 (10.05)	28 (13.02)	6 (8.00)	49 (9.14)
2000-4000	376 (45.52)	107 (49.77)	34 (45.33)	235 (43.84)
4001-6000	155 (18.77)	37 (17.21)	8 (10.67)	110 (20.52)
6001-10000	88 (10.65)	19 (8.84)	10 (13.33)	59 (11.01)
>10000	124 (15.01)	24 (11.16)	17 (22.67)	83 (15.49)

4.2 Public transport mode choice and physical and mental health

Table 3 shows the modelling results of public transport mode choices and physical and mental health outcomes. Model 1 and Model 2 showed that PCS increased for mixed-mode users, and the results remained significant after adjusting for the self-reported health status variables (N=826, Model 1: p=0.005; Model 2: p=0.003). Model 3 and Model 4 were models assessing the relationships of public transport mode choices with MCS, but no significant association was found.

In the sensitivity test, the results on the above relationships persisted (Appendix table A1, A2). Physical health was positively associated with mixed-mode users in metro and non-metro areas, adjusting for all covariates (Metro areas: N=631, p=0.018; Non-metro areas: N=195, p=0.039). The association between mode choice and mental health remained insignificant in the two sensitivity tests.

Table 3. Associations of public transport mode choice and physical and mental health

	PCS						MCS					
	Unadjusted		**Model 1**[a]		**Model 2**[b]		**Unadjusted**		**Model 3**[c]		**Model 4**[d]	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Public transport use												
Travel mode choice												
Bus use only (reference)												
Metro use only	1.972	0.172	1.524	0.276	1.621	0.188	0.864	0.401	0.811	0.434	0.844	0.434
Mixed mode	**3.852**	**0.002**	**3.373**	**0.005**	**2.639**	**0.003**	0.271	0.815	0.146	0.902	-0.405	0.740
Individual Factors												
Female	0.077	0.926	0.023	0.977	-0.231	0.765	-0.091	0.778	-0.065	0.870	-0.313	0.519
Age	**-0.201**	**0.001**	**-0.164**	**0.008**	**-0.095**	**0.016**	-0.003	0.953	0.016	0.738	0.076	0.103
Monthly income												
< 2000 (reference)												
2000-4000	1.331	0.212	1.329	0.296	1.026	0.345	0.305	0.887	0.272	0.900	-0.159	0.941
4001-6000	1.576	0.137	1.053	0.415	0.554	0.672	**2.411**	**0.051**	**2.430**	**0.049**	1.801	0.364
6001-10000	1.519	0.267	1.012	0.376	-0.109	0.883	0.990	0.666	0.958	0.675	-0.154	0.941
>10000	**2.778**	**0.047**	1.991	0.190	1.294	0.345	1.888	0.073	1.856	0.063	1.133	0.251
Health-related variables												
Physical activity												
Low (reference)												
Moderate	**6.021**	**<0.001**			**4.020**	**0.004**	**7.917**	**0.044**			**6.163**	**0.047**
High	**9.775**	**<0.001**			**6.231**	**0.002**	**9.844**	**0.031**			**7.325**	**0.050**
Have chronic disease	**-4.731**	**0.001**			**-1.918**	**0.011**	**-2.705**	**0.011**			-0.307	0.456
Perceived mobility impacts												
Not at all (reference)												
A little	**-2.216**	**0.026**			**-2.092**	**0.032**	**-1.835**	**0.034**			-1.565	0.100
Some	**-6.399**	**<0.001**			**-5.347**	**<0.001**	**-5.276**	**0.003**			**-5.062**	**0.007**
A lot	**-9.451**	**<0.001**			**-8.020**	**<0.001**	**-9.258**	**0.004**			**-8.954**	**0.005**
Extremely	**-14.870**	**<0.001**			**-12.036**	**<0.001**	**-11.510**	**0.011**			**-10.854**	**0.027**
Constant			**53.791**	**<0.001**	**47.677**	**<0.001**			**49.572**	**<0.001**	**41.372**	**<0.001**
R-square			0.071		0.243				0.056		0.348	
N (participants)	826		826		826		826		826		826	

Notes:

Significant results are shown in bold font.

[a] Model 1 controlled for gender, age, and monthly income.

[b] Model 2 controlled for all variables in Model 1 plus physical activity, chronic disease and their mobility impact.

[c] Model 3 controlled for gender, age, and monthly income.

[d] Model 4 controlled for all variables in Model 3 plus physical activity, chronic disease and their mobility impact.

4.3 The route environment and physical and mental health

4.3.1 Mixed-mode users

Table 4 shows the modelling results of the relationship between route environment and physical and mental health for mixed-mode users (N=536). For physical health, walking less than 10 minutes to the normally used metro station predicted a higher PCS (Model 5: p=0.002, Model 6: p=0.028). Both moderate and high levels of pedestrian crowdedness were negatively associated with PCS in Model 5 (p≤0.051), and the high level of pedestrian crowdedness remained significant after adjusting for the self-reported health status variables in Model 6 (p=0.016). High satisfaction in sidewalk width was positively associated with PCS in Model 5 (p<0.043), but became insignificant after adjusting for the self-reported health status variables. For mental health, walking less than 10 minutes to the normally used bus stop increased MCS (Model 7: p=0.026, Model 8: p=0.021). A moderate level of satisfaction in sidewalk width was positively associated with MCS in Model 7 (p<0.016). A high level of sidewalk width satisfaction had a greater likelihood with better MCS in Model 7 and Model 8 (p<0.078).

Table 5 shows the sensitivity test results for mixed-mode participants in metro areas (N=456 out of 631). A shorter walking time to the normally used metro station was associated with a higher PCS (Model 9: p=0.031; Model 10: p=0.057). Pedestrian crowdedness had a persistent negative association with PCS (p ≤ 0.055). Higher satisfaction in sidewalk width was associated with a higher MCS (p≤0.026). Shorter walking time to the normally used bus stop was associated with better mental health (p=0.056). Participants who reported a moderate degree of pedestrian crowdedness to the metro station were more likely to have lower MCS (Model 11: p=0.026; Model 12: p=0.036). We put the sensitivity test results of mixed-mode users in the non-metro area in the Appendix (Table A3, N=83 out of 195). A higher level of satisfaction in sidewalk width could increase participants' PCS (p≤0.049). Shorter walking time to the normally used bus station was associated with a higher MCS (p=0.056), but this effect was not observed after adjusting for the self-reported health status variables.

Table 4. Associations of route environment and physical and mental health for mixed-mode users

	PCS						MCS					
	Unadjusted		**Model 5^a**		**Model 6^b**		**Unadjusted**		**Model 7^c**		**Model 8^d**	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Route environments												
To bus stop												
Walking barriers	-0.483	0.645					-1.326	0.355	-0.988	0.596	-1.007	0.552
Walking time < 10 mins	0.341	0.674					**1.902**	**0.025**	**1.944**	**0.026**	**1.612**	**0.021**
Rest area condition												
Low (reference)												
Moderate	1.524	0.133	1.411	0.295	0.401	0.841	0.395	0.897				
High	0.159	0.905	0.185	0.982	-0.128	0.887	-0.078	0.754				
Pedestrian crowdedness												
Low (reference)												
Moderate	-1.214	0.245	-0.465	0.770	-0.447	0.749	-0.409	0.626				
High	-0.583	0.733	-0.314	0.951	-0.319	0.952	1.195	0.557				
Sidewalk width satisfaction												
Low (reference)												
Moderate	1.389	0.524	2.259	0.298	0.993	0.582	**3.597**	**0.008**	**3.371**	**0.016**	2.385	0.102
High	1.904	0.207	**3.113**	**0.037**	2.139	0.353	**3.596**	**0.049**	**3.281**	**0.041**	**2.834**	**0.056**
To metro station												
Walking barriers	-1.251	0.272					-0.159	0.887				
Walking time < 10 mins	**1.561**	**0.037**	**1.861**	**0.002**	**1.407**	**0.028**	0.354	0.559				
Rest area condition												
Low (reference)												
Moderate	1.261	0.223	1.055	0.293	0.685	0.364	-0.512	0.565				
High	0.099	0.920	-0.135	0.898	-0.179	0.988	1.231	0.256				
Pedestrian crowdedness												
Low (reference)												
Moderate	**-2.229**	**0.008**	**-2.650**	**0.051**	-1.243	0.151	-1.213	0.201	-1.471	0.131	-0.260	0.731
High	**-2.703**	**0.049**	**-3.067**	**0.015**	**-2.129**	**0.016**	-0.877	0.502	-1.469	0.214	-0.313	0.680
Sidewalk width satisfaction												
Low (reference)												
Moderate	1.389	0.524	2.259	0.108	0.993	0.235	**3.597**	**0.033**	**3.371**	**0.026**	2.385	0.120

	PCS						MCS					
	Unadjusted		Model 5[a]		Model 6[b]		Unadjusted		Model 7[c]		Model 8[d]	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
High	1.904	0.209	3.113	0.043	2.139	0.116	**3.596**	**0.049**	**3.281**	**0.063**	**2.834**	**0.078**
Individual Factors												
Female	-0.443	0.473	-0.481	0.347	-0.616	0.235	0.657	0.222	0.792	0.341	0.757	0.357
Age	**-0.187**	**0.001**	**-0.198**	**<0.001**	**-0.080**	**0.049**	-0.026	0.660	-0.018	0.431	0.053	0.378
Monthly income												
< 2000 (reference)												
2000-4000	0.544	0.659					-0.156	0.668				
4001-6000	0.709	0.514					1.413	0.370				
6001-10000	0.456	0.797					-0.476	0.555				
>10000	2.096	0.084					1.519	0.359				
Health-related variables												
Physical activity												
Low (reference)												
Moderate	**6.677**	**0.001**			**4.875**	**0.008**	**7.403**	**0.006**			**6.032**	**0.005**
High	**10.233**	**<0.001**			**7.000**	**0.001**	**9.039**	**0.001**			**6.413**	**0.013**
Have chronic disease	**-6.187**	**<0.001**			**-3.468**	**0.002**	**-2.211**	**0.032**			0.211	0.879
Perceived mobility impacts												
Not at all (reference)												
A little	**-2.845**	**0.001**			-1.540	0.190	-0.959	0.224			-0.753	0.340
Some	**-6.569**	**<0.001**			**-4.835**	**0.006**	**-6.416**	**0.001**			**-6.462**	**0.007**
A lot	**-11.249**	**<0.001**			**-9.008**	**0.001**	**-8.059**	**0.001**			**-7.353**	**0.041**
Extremely	**-15.430**	**<0.001**			**-11.878**	**<0.001**	**-18.352**	**<0.001**			**-17.621**	**<0.001**
Constant			**61.038**	**<0.001**	**50.910**	**<0.001**			**53.279**	**<0.001**	**43.074**	**<0.001**
R-square			0.083		0.367				0.086		0.261	
N (participants)	536		536		536		536		536		536	

Notes:

Significant results are shown in bold font.

[a] Model 5 controlled for gender and age.

[b] Model 6 controlled for all variables in Model 5 plus physical activity, chronic diseases, and their impact on mobility.

[c] Model 7 controlled for gender, age, and monthly income.

[d] Model 8 controlled for all variables in Model 7 plus physical activity, chronic diseases and their mobility impact.

Table 5. Associations of route environment and physical and mental health for the mixed-mode public transport use group **in the metro area**

	PCS						MCS					
	Unadjusted		**Model 9^a**		**Model 10^b**		**Unadjusted**		**Model 11^c**		**Model 12^d**	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Route environments												
To bus stop												
Walking barriers	-0.861	0.227					-1.333	0.253				
Walking time < 10 mins	0.373	0.632					1.428	0.088	1.400	0.109	**1.463**	**0.056**
Rest area condition												
Low (reference)												
Moderate	1.853	0.215	1.719	0.142	1.426	0.212	0.170	0.655				
High	0.365	0.726	0.437	0.676	0.361	0.723	-0.885	0.446				
Pedestrian crowdedness												
Low (reference)												
Moderate	-1.396	0.066	-0.557	0.498	-0.540	0.501	-0.837	0.589				
High	-1.021	0.814	-0.999	0.622	-1.028	0.603	0.450	0.841				
Sidewalk width satisfaction												
Low (reference)												
Moderate	0.717	0.624					**4.157**	**0.008**	**4.359**	**0.005**	**4.215**	**0.008**
High	1.769	0.298					**3.553**	**0.037**	**3.569**	**0.026**	**3.534**	**0.050**
To metro station												
Walking barriers	-1.702	0.201	-1.101	0.420	-1.566	0.241	-0.186	0.900				
Walking time < 10 mins	1.369	0.060	**1.714**	**0.031**	**1.473**	**0.057**	0.584	0.501				
Rest area condition												
Low (reference)												
Moderate	1.549	0.078	1.290	0.152	1.348	0.124	-0.466	0.645	-0.213	0.835	-0.155	0.879
High	0.074	0.745	-0.017	0.987	-0.025	0.980	1.488	0.268	1.966	0.083	1.942	0.085
Pedestrian crowdedness												
Low (reference)												
Moderate	**-2.600**	**0.001**	**-2.906**	**0.002**	**-2.841**	**0.002**	-1.553	0.068	**-1.950**	**0.026**	**-1.970**	**0.036**
High	**-2.935**	**0.022**	**-2.755**	**0.038**	**-2.486**	**0.055**	-1.909	0.188	-2.462	0.090	-2.311	0.109
Sidewalk width satisfaction												
Low (reference)												
Moderate	0.717	0.524					**4.157**	**0.050**	**4.359**	**0.012**	**4.215**	**0.022**
High	1.769	0.268					**3.553**	**0.033**	**3.569**	**0.026**	**3.534**	**0.026**

	PCS						**MCS**					
	Unadjusted		**Model 9**[a]		**Model 10**[b]		**Unadjusted**		**Model 11**[c]		**Model 12**[d]	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Individual Factors												
Female	-0.961	0.117	-1.004	0.199	-1.365	0.075	0.686	0.435	0.853	0.340	0.763	0.392
Age	**-0.172**	**0.001**	**-0.183**	**0.001**	**-0.148**	**0.009**	-0.028	0.668	-0.020	0.898	0.000	0.996
Monthly income												
< 2000 (reference)												
2000-4000	1.100	0.454	1.307	0.371	0.579	0.658	-0.039	0.981	0.217	0.895	-0.038	0.981
4001-6000	1.099	0.568	1.112	0.480	0.733	0.604	1.280	0.471	1.734	0.329	1.294	0.669
6001-10000	1.260	0.987	1.210	0.508	-0.319	0.845	-0.672	0.226	-0.786	0.598	-1.090	0.593
>10000	2.577	0.117	2.018	0.215	0.712	0.624	2.387	0.190	2.768	0.131	2.697	0.139
Health-related variables												
Physical activity												
Low (reference)												
Moderate	**6.927**	**0.023**			**6.377**	**0.039**	**8.226**	**0.021**			**7.851**	**0.026**
High	**10.780**	**0.001**			**10.093**	**0.001**	**9.359**	**0.007**			**9.051**	**0.009**
Have chronic disease	-6.397	0.388					**-2.359**	**0.030**				
Perceived mobility impacts												
Not at all (reference)												
A little	-2.580	0.266					**-1.003**	**0.340**				
Some	-6.144	<0.387					**-6.742**	**<0.001**				
A lot	-12.088	<0.299					**-8.602**	**<0.001**				
Extremely	-17.868	<0.784					**-17.297**	**<0.001**				
Constant			**47.761**	**0.232**	**41.646**	**0.014**			**54.322**	**0.093**	**63.074**	**0.025**
R-square			0.243		0.248				0.138		0.233	
N (participants)	456		456		456		456		456		456	

Notes:

Significant results are shown in bold font.

[a] Model 9 controlled for gender, age, and monthly income.

[b] Model 10 controlled for all variables in Model 9 plus physical activity.

[c] Model 11 controlled for gender, age, and monthly income.

[d] Model 12 controlled for all variables in Model 11 plus physical activity.

4.3.2 Single-mode choices of public transport use

As single-mode choices were not significantly associated with physical and mental health outcomes, we thus put all modelling results on the health impacts of the route environment for single-mode choices (e.g., bus-only, metro-only) into Appendix (Table A4 and A5). For bus-only users (N=215), participants with higher satisfaction in sidewalk width had better physical health ($p \leq 0.022$). No significant association was found between the route environment and mental health. For metro-only users (N = 75), high satisfaction in sidewalk width was positively associated with PCS ($p \leq 0.034$), while pedestrian crowdedness was negatively associated with MCS ($p=0.001$).

In the sensitivity test, higher satisfaction in sidewalk width was associated with better PCS ($p \leq 0.004$) for bus-only users in metro areas (N=103). No significant association was found between route environment and mental health. Similar results were found in the metro-only group in metro areas (N=72). Moreover, high satisfaction in sidewalk width persistently contributed to improved health by increasing PCS ($p \leq 0.014$) for the bus-only users in non-metro areas (N=112). Pedestrian crowdedness was a steady predictor of mental health, with an adverse effect for the respondents who reported a high degree of crowdedness ($p \leq 0.022$). As no participants were solely dependent on the metro in this area, we did not run the models for the metro-only group.

5 Discussion

In this paper, we investigated the travel-related health effects of multiple public transport mode choices and the route environments in a metro-led TOD city. As expected, older people preferred to use multiple public transport options rather than single-mode usage, such as metro use only. This travel preference was positively associated with their physical and mental health. We also expected that the route-environment characteristics in the TOD city might modify the relationships between modal choice and health outcomes among these people. The findings somewhat confirmed this hypothesis, revealing that shortening walking time, widening sidewalk width and reducing crowdedness could effectively promote health among older adults. However, we did not find walking barriers and rest area conditions associated with health outcomes.

5.1 The importance of multiple public transport options in TOD cities

We found that using multiple public transport modes was the most popular travel choice among older people, and their mode preferences decreased to bus-only and then to metro-only. Mixed-mode users had better physical and mental health compared to single-mode users. This result coincides with that of Wong's (2018) research, demonstrating that a combination of bus and metro was most frequently chosen for daily travel among older people for reasons of convenience, reliability and travel stability. A study conducted by Muley (2009) confirmed that combined trips made by train and bus were most common in Australian TOD neighborhoods.

Our study provided evidence on the central role of multiple mode choices regarding older people's public transport use patterns. It further showed a different distribution under the single-mode-usage category — there were more bus-only users than metro-only users. Our result suggested that older people prefer public buses to the metro, while combining the usage of bus and metro may better meet their travel needs and preferences. Our descriptive results also imply a linkage between using multiple public transport options and health outcomes among older people. Although public bus services gradually become metro feeders, the findings suggested that the public bus remains an indispensable transport option for older people living in a metro-led TOD city.

5.2 Association between multiple public transport options and health outcomes

Our models found an association between mixed-mode usage and physical health. Mixed usage of bus and metro was associated with better physical health than those who rely on a single mode. This result persisted in several sensitivity tests. Using survey data collected in seven American TOD cities, Langlois et al. (2016) explored the public health benefits of public transport use (e.g., bus, metro and other public transport options). They found that the participants with higher levels of public transport use were more likely to achieve an increase in physical activity. A study in England demonstrated that bus use was associated with healthy aging, including lower Body Mass Index (Webb et al., 2016). Daniele et al. (2021) found better physical conditions correlated to frequent use of local public transport.

Our analyses directly compared the health outcomes between multiple and single mode choices, which was rarely explored in previous studies. The results confirmed the significant role of multiple public transport options. We offer evidence on the association between multiple mode choices and health outcomes, supporting the assumption that using multiple public transport options is crucial for older people in TOD cities. Meanwhile, our study area is a transit-oriented city in Hong Kong, which is a representative of Asian high-density cities. The city relies on the metro as the backbone of the public transport system to sustain its built environment, and, like other cities in Asia, its population is experiencing rapid aging (Sun et al., 2021). This study provided empirical evidence on how TOD development can affect older people's health. Although increasing attention is given to the travel pattern and health outcomes of older people worldwide, most research has been conducted in Western cities (e.g., United States, Australia, and Europe) (Yang, 2018; Szeto et al., 2017). A study in California (United States) suggested new light rail transit line could significantly increase people's physical activity and health (Hong et al., 2016). The older people's free bus pass scheme in the United Kingdom effectively increased their use of public transport and thus improved physical and mental health (Webb et al., 2012; 2016). However, it is speculated that these results were restricted to travel experiences in the Western context, where the residents depend on driving as the main travel mode rather than on public transport systems, and poor transport systems and connections may hinder older people's ability to get out of the home. The limited studies conducted in other Asian cities, such as Shanghai (Chen et al., 2017) and Singapore (Song et al., 2020), focused on the relationship between general public transport use, access to public transport and physical health. Little attention has been paid to how different public transport options influence older adults' physical and mental health. Therefore, evidence from a case city of Hong Kong may provide insights into how multiple public transport options can contribute to older people's overall health.

5.3 The role of the route environment under specific mode use

Among the mixed-mode users, we found that short walking time to the normally used bus stop or metro station was positively associated with physical and mental health. Specifically, walking less than 10 minutes from home to the bus stop was associated with better mental health, while walking less than 10 minutes from home to the metro station was associated with better physical health. A cross-sectional study by Wong et al. (2018) proved that walking time is one of the main determinants of daily travel and physical activity. Schorr and Khalaila (2015) found that proximity to service and transport could be associated with better mental wellbeing and quality of life. Our results detailed how walking time is associated with health outcomes for different mode choices and found that mixed-mode users were more likely to report health benefits brought by short walking time than single-mode users.

We also found that a higher level of satisfaction in sidewalk width was positively associated with older people's physical and mental health. The findings are consistent with a previous study indicating that low effective sidewalk width is a significant obstacle to the mobility of older people (Titheridge et al., 2009), and that ample sidewalk widths may encourage older people to increase physical activity (Duncan et al., 2021). Our results suggested that the association between satisfaction in sidewalk width and health outcomes persisted, whether in the access to bus stops or metro stations. We also examined the associations between route environments with different travel modes. The results are heterogeneous: sidewalk width satisfaction tends to affect the mental health of mixed-mode users, while it affects the physical health of single-mode users; this association is also robust in the sensitivity tests.

Moreover, we found that pedestrian crowdedness on the route to the normally used metro station was negatively associated with health outcomes. Previous findings showed crowdedness during travelling is a major issue that increases the health risks of older people (e.g., psychological or emotional distress), especially when taking the metro (Li & Hensher, 2013). Mouratidis and Yiannakou (2022) also found lower density and crowdedness were associated with better health and wellbeing outcomes. Our research focuses on the health effects of pedestrian crowdedness. It implies that overcrowded sidewalks might discourage mobility and thus negatively affect the health of older people. Our findings further unravel a differentiated health effect of pedestrian crowdedness among different mode choices: such health impact is mainly on the physical health of mixed-mode users, while it is mainly on the mental health of metro-only users.

5.4 Limitations and strengths

Our study has several limitations. First, we measured multiple public transport options as a combination of bus and metro, as bus and metro services are preferred over other transport options in Hong Kong; but other combinations such as “bus and trams” and “metro and taxi” were not discussed. Second, we used baseline data in this study, which restricted the ability to make causal inferences between public transport use and health outcomes of older people from this cross-sectional data. Comparing before-and-after data within the natural experiment design will help the causal inference further (Sun et al., 2021). Third, qualitative data might help to explain the finding of our current quantitative baseline data alone. Finally, we used Hong Kong as the case city. The results may not apply to other contexts. Finding generalizability needs caution.

This study also has several strengths. The study provided new evidence regarding mode choice and health outcomes of older people in a TOD city. Previous research mainly focused on comparing public transport and other modes (e.g., car, walking and cycling). In contrast, we examined how multiple public transport options related to the health of older people, offering insights into the relationship between travel behavior and health. This information might contribute to the design and implementation of TODs that could better support actively aging. Another strength lies in the statistical analysis method used in this study, which is robust. We conducted the multivariable linear regression analyses, with several sensitive tests, to assess the associations between route environment and health outcomes stratified by different mode choices, which increased our results’ credibility.

6 Conclusion

Population aging poses a significant challenge in creating age-friendly environments which encourage older people to stay active and healthy. This study focuses on multiple public transport options and the associated route environments, which can affect the mobility of older people and, hence, are related to their physical and mental health in transit-oriented cities. When an older person adopts multiple public transport modes and is satisfied with the route environment, it could help with healthy aging. As such, it is critical to consider the travel requirements of older people when implementing TODs, to provide a well-organized multimodal public transport system and pedestrian-friendly route environments and, in so doing, to improve the health of older people. Our results will help policymakers, urban planners, and other stakeholders evaluate the quality of public transport systems and associated route environments concerning the specific needs of older people and develop strategies for advancing age-friendly urban development in transit-oriented cities.

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Appendix

Appendix available as a supplemental file at https://jtlu.org/index.php/jtlu/article/view/2152

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