Associations between the Urban Environment and Outdoor Walking Mobility by Cognitive Functioning in a Group of Older Adults in Singapore

Yuezhong Liu (yz.liu@ntu.edu.sg)
Nanyang Technological University
Chek Hooi Wong
National Innovation Challenge/NMRC Singapore
Noam Shoval
Hebrew University of Jerusalem
Ringo Moon-Ho Ho
Nanyang Technological University
Yin-Leng Theng
Nanyang Technological University

Research Article

Keywords: Cognitive Impairment, Daily life gait speed, Gross Plot Ratio, Land Use

Posted Date: January 5th, 2024

DOI: https://doi.org/10.21203/rs.3.rs-3822075/v1

Additional Declarations: No competing interests reported.

Abstract

Objectives: This study aims to examine the relationship between the outdoor mobility of older adults with and without cognitive impairment and the built environment in three urban neighbourhoods in Singapore.

Methods: Outdoor walking mobility in daily life gait speed (DGS) was collected continuously for one week using a previously validated hybrid mobility tracker. Mini-Mental State Examination (MMSE) cut-offs by educational levels were used to differentiate cognitive impairment (CI) and without cognitive impairment (non-CI). The environmental characteristics examined were gross plot ratio and land use. Statistical correlations (one-way ANOVA test and linear regression) were used to examine the associations between older adults' outdoor mobility and built environment for all CI and non-CI groups. A case example was also used to provide a location-based heatmap on DGS for 2 older adults (CI and non-CI) navigating the same neighbourhood for 3 consecutive days.

Results: Thirty-three participants registered a total of 2,428 kilometres with an average DGS of 0.74 m/s outside of their homes over a period of 220 days. The mean (SD) age of the participants was 69.2 (7.14), and 21 (64%) of them were female. Fourteen of the (42%) participants were classified as cognitive impaired. Overall, a higher gross plot ratiowas found to be associated with faster outdoor gait speed (DGS) for the non-CI group ($\beta = 0.04$, $r = 0.69$, $p =.03$) and slower DGS for the CI group ($\beta = -0.13$, $r = 0.75$, $p =.01$). The DGS of individuals with CI was slower than that of non-CI individuals, with the greatest difference observed in business and commercial areas; however, the DGS of individuals with CI was faster than that of non-CI individuals within community and residential locations.

Conclusions: Individuals with CI had a slower outdoor gait speed and may require higher adaptation to the environment. Although DGS could be used in differentiating older adults with and without cognitive impairment while mobilizing in an urban environment, considerations should also be given to understanding the interaction of DGS with different land use and typology.

1. Background

The relationship between the environment and cognitive functioning for older adults has been an area of growing interest in recent years. Research in this area has focused on identifying environmental factors that may promote or impair cognitive health in older adults (Gatto et al., 2014; Ngandu et al., 2015; Wu et al., 2011). There is a growing body of evidence suggesting that various factors, including social connections (Fratiglioni et al., 2000; Seeman et al., 2001), physical environments (Berman et al., 2008; Power et al., 2011; Weuve et al., 2012), and urban morphology (Cho & Rodriguez, 2015; Giles-Corti et al., 2016; Kaspar et al., 2015; Power et al., 2011), can have significant impacts on cognitive function in older adults.

Recent studies have shown that daily life gait speed (DGS) was associated with cognitive health in older adults (Del Pozo Cruz et al., 2022; Seo et al., 2023). DGS has also been shown to be a useful predictor of a wide range of health outcomes, including cognitive function, functional status, and mortality risk.

Slower DGS is associated with poorer cognitive performance, increased risk of cognitive decline, and higher risk of dementia in older adults (Seo et al., 2023). Additionally, improvements in DGS have been linked to improvements in cognitive function and reduced risk of cognitive decline (Chung et al., 2022; Chung et al., 2021). Researchers have also examined the relationships of mobility with other spatial-temporal indicators. Yin et al. (2013) delineated the relationships between mobile distance and area. Crane et al. (2022) also found that walking distance and other mobility indicators were correlated with clinical measures of executive function and walking endurance. Kawai et al. (2021) also found that DGS is the fastest early in the morning and slower in the afternoon and evening. Specifically, Wettstein et al. (2015) found that a high proportion of cognitively impaired individuals in the mobility-restricted cluster and exhibiting restricted mobility patterns were also associated with older ages, worse health outcomes, and a lower out-of-home activity level. Shoval et al. (2011) found that the mobility of older adults with cognitive impairment is severely restricted, with most out-of-home time spent in close proximity to their residences.

Overall, existing studies typically involve tracking participants' movements using Global Positioning System (GPS) devices over an extended period, collecting mobility data on DGS to undifferentiated locations, such as parks, community centres, and shopping areas. There is limited research on the impact of built environment such as Gross Plot Ratio and Land Use on the walking patterns of individuals with cognitive impairment. This study aims to explore the relationships between the land use typologies of the built environment and DGS measured by cognitive functioning in older adults.

2. Methods

2.1 Study Design

This study was a secondary data analysis of cross-sectional data from a national-level project on urban planning and design of age-friendly neighbourhoods in Singapore where three study neighbourhoods (each 1 km^2) were selected a priori from the western, central and eastern parts of Singapore based on a high proportion of older adults (aged ≥ 55 years old). Details of this study have been described in (Ho et al., 2020) elsewhere.

2.2 Participants

Thirty-three older community-dwelling adults, 55 years and above, resided in 3 urban subzones (S1, S2, S3) in Singapore. For current study, “neighbourhood” is defined as a 400 - 1000 m buffer around the home (any ref to cite?). Only those residents resided in up to a 1 km buffer around the subzone were qualified for participation. Participants put on a wearable hybrid GPS and accelerometer tracker when going outdoors continuously for 7 days (Ho et al., 2020). The tracker was designed to capture the wearer’s geospatial data accurately within 15 m (depending on the GPS signal) during outdoor travel or activity to enable the geographic positioning of the participant in longitude and latitude and the travel mode speed.

2.3 Dataset

2.3.1 Individual Data

Basic sociodemographic, cognitive data and DGS were collected (, DGS was also collected. (Table 1). The estimated average speed was calculated based on a continuous walking track and a GPS distance of less than 10 km (Tudor-Locke et al., 2011).

Table 1
List of objective daily life outdoor mobility variables.

Mobility indicators (per day)	**Unit**	**Sources**	**Derivations**
Daily life Gait Speed (DGS)	m/s	Accelerometer	Average speed of a continuous walking track. Derived using a combination of 1-week GPS and accelerometer data. Only outdoor walking was considered for this measure for longer and regular ambulation bouts, and GPS distance ≤ 10 km ((Del Pozo Cruz et al., 2022; Seo et al., 2023))

2.3.2 Gross Plot Ratio and Land Use

The gross plot ratio (GPR), monitored by the Urban Redevelopment Authority of Singapore (URA), reflects how intensively the land parcel can be utilized. The GPR of land parcels are revised in the Draft Master Plan and subsequently, the Master Plans (MP), along with their respective Land Uses. Both GPR and land use are used as indicators of development control and land use in different areas of the city in addition to being used for cost forecasting and resourcing a given construction quality (Cheng, 2009; Menz et al., 2014). URA (2019) described the full details of the land use map of Singapore. There are 31 categories of zoning interpretation, such as residential, commercial, hotel, business park, waterbody, and transport facilities. Table 2 shows the general considerations of the development control of GRP and building storeys. If two plots of land have similar areas (on the URA Space map Fig. 1) but differing plot ratios, it usually means that one will be denser or taller than the other[1].

Table 2
General considerations of development control from URA (Menz et al., 2014).

Gross plot ratio/density	Storeys
1.4 (very low density)	5
1.6 (low density)	12
2.1 (medium density)	24
2.8 (high density)	36
> 2.8 (very high density)	> 36

2.4 Data analyses

DGS was analysed and mapped by Python 3.8.0. One-kilometre buffers around the perimeter of each subzone were created, and the environmental features within were assessed. Statistical analysis was performed using the SciPy 1.90 package in Python 3.8.0. Gross Plot Ratio and Land Use were retrieved for statistical analysis by the public Application Programming Interface (API) from the Master Plan Map (URA, 2023). One-way ANOVA was used to test for differences between two groups. All significant differences were evaluated at a α-value of 0.05.

3. Results

3.1 Participants’ characteristics

Of 33 participants, 18 were from S1, 8 were from S2 and 7 were from S3. Socio-demographics are shown in Table 3. The mean (SD) age of the samples was 69.2 (7.14) years, 21 of them (64%) were females and majority were Chinese (31, 94%). Half were married, with only 42% having completed secondary school or higher in education. The average number of schooling was 7.3 (4.19) years. None of the participants had full-time employment, with 18% holding part-time employment. Majority of participants lived in public housing (95%) and lived in their respective subzones for an average of 23.1 (SD = 15.2) years. All participants had no previous clinical diagnosis of dementia.

Table 3
Soci-demographics for the three subzones. (n = 33).

Demographics	S1 (n = 18)	S2 (n = 8)	S3 (n = 7)
Age, mean (SD)	71.4 (6.43)	63.3 (4.86)	70.0 (8.00)
Female, n (%) 14 (77.8) 4 (50.0) 3 (42.9)			
Ethnicity, n (%)			
Chinese	18 (100)	6 (75)	7 (100)
Malay	0	2 (25)	0
Highest education completed, n (%)			
No formal education	1 (5.6)	2 (25.0)	0
Primary school	2 (50.0)	3 (37.5)	3 (42.9)
Secondary school	4 (22.2)	2 (25.0)	2 (28.6)
Post-secondary	1 (5.6)	1 (12.5)	1 (14.3)
Tertiary	3 (16.7)	0	0
Don’t know/Not sure	0	0	1 (14.3)
Housing type, n (%)			
HDB 1-2 room	3 (16.7)	0	0
HDB 3 room	10 (55.6)	0	5 (71.4)
HDB 4 room	3 (16.7)	6 (75.0)	0
HDB 5 room/HUDC/Executive flat	1 (5.6)	2 (25.0)	2 (28.6)
Condo/Apartment	1 (5.6)	0	0
Number of years of schooling, median (SD)	6 (0-16)	7 (0-13)	6 (3-10)
Number of years retired, median (range)	16 (8-30)	2 (1-9)	6 (1-22)
Number of years living here, median (range)	20 (0.5-50)	20 (8-32)	25 (4-50)
MMSE score, mean (SD) (max 30)	27.2 (2.32)	26.4 (2.13)	26.6 (2.22)
Cognitive impairment (MMSE cut-offs), n (%)	6 (33.3)	4 (50.0)	4 (57.1)

* Housing and Development Board (HDB) is Singapore’s Public Housing, Condo/Apartment is Private housing

3.2 Outdoor Mobility by Cognitive Impaired and Non-Impaired Participants

The travel mode of the participant was determined by travel speed. A travel speed less than 1.39 m/s (5 km/h) was categorized as walking mode, and a speed above 1.39 m/s (5 km/h) was categorized as vehicular mode (Bohannon & Williams Andrews, 2011; Schimpl et al., 2011). Neighbourhoods were defined as the respective subzones and a 1 km buffer (Oliver et al., 2007). Table 3 shows all GPS records (a total of 5,583,089 records per second). Overall, the DGS is 0.74 m/s (2.66 km/h) (Table 4).

Table 4
Outdoor mobility by impaired and non-impaired participants. (n = 33).

Description	**Total Sample (N = 33)**	**Cognitively Non-Impaired (non-CI) (n = 19)**	**Cognitively Impaired (CI) (n = 14)**
Outdoor Mobility			
Daily life Gait Speed (DGS) (m/s), mean (SD)	0.74 (0.11)	0.75 (0.12)	0.73 (0.08)

3.3 Outdoor Mobility with Gross Plot Ratio and Land Use

Based on the one-way ANOVA test, both groups' DGS was correlated with GPR Non-CI ($F = 77.13$, $p < .01$) and CI ($F = 111.39$, $p < .01$). Linear regression shows that a higher GRP was found to be associated with faster outdoor gait speed (DGS) for non-CI individuals ($\beta = 0.04$, $r = 0.69$, $p = .03$) and slower DGS for CI individuals ($\beta = -0.13$, $r = 0.75$, $p = .01$). This means that non-CI older adults walk slower in a low-intensity built area (surrounding low-rise buildings) and walk faster when they are in a high-intensity built area (surrounding high-rise buildings). In contrast, CI older adults walk faster in a low-intensity built area while walking slower when they are in a high-intensity built area. Figure 2 shows the correlation between daily life gait speed (m/s) and gross plot ratio by CI and non-CI groups. Figure 3 shows the total time spent across each gross plot ratio. Figure 4 indicates the relationship between land use and outdoor gait speed (m/s). Figure 5 shows the total time spent across each land use. Overall, non-CI participants spent more time walking outdoors (2279.07 minutes/week) than CI participants (1818.00 minutes/week). Both the CI and non-CI groups spent most of their time walking in their residential area. When stratified by land use typology, the CI group walked slower than the non-CI business (CI: 0.65 m/s; non-CI: 0.72 m/s) and commercial (CI: 0.67 m/s; non-CI: 0.76 m/s) zones. Conversely, CI walk faster than non-CI groups within the community (defined by land use area containing health and medical care) (CI: 0.70 m/s; non-CI: 0.67 m/s) and residential zone areas (CI: 0.80 m/s; non-CI: 0.62 m/s) (Fig. 4). Both CI and non-CI participants spent most of their time at gross plot ratios from 2.8 to 3.0 (Fig. 3), and non-CI older adults spent more time walking (CI: 1531.00 minutes/week; non-CI: 2214.70 minutes/week) in residential areas (Fig. 5).

4. Discussion

4.1 Daily Life Gait Speed (DGS) with Built Environment

There are significant differences in the mobility of CI and non-CI samples between DGS and built environment variables (gross plot ratio and land use) in Fig. 3 and Fig. 4. Cognition plays an important role in outdoor mobility for older adults in the community. Cognition in the form of executive function plays an important role in the ability to perform both motor and cognitive tasks simultaneously in old adults while navigating outdoors (Hausdorff et al., 2008; Lamoth et al., 2011). Lamoth et al. (2011) also suggested that changes in cognitive functions contribute to changes in gait variability and stability and walking under dual-task conditions. There were small differences in DGS for both non-CI (0.75 m/s) and CI (0.73 m/s). However, when stratified according to land use, our study showed a larger differentiation in DGS. Non-CI older adults walk slower than CI older adults in a low GPR (low dense building development) and in community and residential zone areas, while non-CI older adults walk faster in a high GPR area (high dense building development) and in business and commercial zone areas. The findings were consistent for both GPR and land use results, as lower GPR is approved for community and residential use, and high GPR is approved for business and commercial use.

Both groups spent the majority of their time walking in residential areas (non-CI: 2214.7 mins, CI: 1531.0 mins), with non-CI spending more time walking. We postulate that CI and non-CI individuals may have different walking behaviours while interacting with different land uses. Various studies have shown that standardized measures such as lower extremity strength and indoor gait speed (Warren et al., 2016, (Lane et al., 2020; Yu et al., 2017)) are important for older adults to interact with their physical environments. However, the measures represent a physiologic potential in mobilizing in the community. Outdoor walking speed is more reflective of real-world interactions with the environment, which may be influenced by cultural, economic, and social factors (Bornstein & Bornstein, 1976; Kirkcaldy et al., 2001; Walmsley & Lewis, 1989).

Non-CI with a lower DGS in community and residential land use may be due to higher levels of interaction and participation with activities in the community for residential use. In Singapore, most residential land use in public housing is self-contained with shops, markets, food stalls and community activity centres, which may slow their outdoor DGS. However, the current study is not able to discern the level of cultural, economic and social participation during the 1 week of monitoring for both groups.

Older adults with CI walked with a lower DGS in business and commercial use, which may indicate a higher need for dual or multitasking. Studies have also indicated both positive and negative effects of the gross plot ratio on DGS (Bornstein & Bornstein, 1976; Kirkcaldy et al., 2001; Walmsley & Lewis, 1989). High GPR may provide shade, protecting pedestrians from excessive heat and improving comfort during walking (Vasilikou & Nikolopoulou, 2020). Additionally, the presence of high-rise buildings as landmarks can aid in wayfinding and orientation, potentially enhancing walking efficiency and speed (Yesiltepe et al., 2021). However, the impact of GPR on DGS should also be considered in the context of wind effects and visual enclosure. High-rise structures can create wind tunnels and turbulent airflows at the street level, impeding walking speed and increasing perceived effort. Furthermore, high-rise buildings can contribute to a sense of visual enclosure, reducing the perceived open space and potentially influencing individuals' walking behaviour (Zarghami et al., 2019). Non-CI with a higher DGS in business and commercial use may be influenced by the above factors.

4.2 Case example of daily life gait speed (DGS) between CI and non-CI individuals in the same neighbourhood

To further understand the differences between CI and non-CI, a case study was performed on two participants with CI (age: 82, male, MMSE: 23) and non-CI (age: 77, female, MMSE: 26) (Fig. 5). The criterion of selection is based on the demographic profiles (live in the same subzone, familiar with the neighbourhood and same age group).

Figure 6 shows the two selected participants' outdoor trajectories for 3 days; the top (a) is a participant with CI, and the bottom (b) represents a participant without CI. Both residents frequented their neighbourhood residential and commercial areas. Using heatmaps of DGS, we were able to visualize their wayfinding and navigation routes. We observed that the participant with CI had a more linear route, while the non-CI participant’s route appeared more complex. The linear trajectory of the CI participant followed a regular path (repetitive) in a relatively constant direction and speed from Day 1 to 3. The non-CI participants had a more heterogeneous and nonlinear trajectory of navigating at different speeds.

Heatmapping and visualization also showed that CI participants walked fast in the neighbourhoods (more red) with a regular daily route. Studies have also shown that familiarity with the environment can have an impact on DGS and the extent of travel (Lu et al., 2018; Van Cauwenberg et al., 2012), especially for persons with dementia (Margot-Cattin et al., 2021). Individuals who are familiar with their surroundings tend to navigate more confidently and efficiently, which can influence their walking speed.

Conclusions

Outdoor walking for older adults who are non-CI and CI involves a complex relationship between intrinsic physiologic and cognitive ability with environmental demands Although we found that on average, the DGS of non-CI older adults is faster than that of CI older adults, the results are not consistent throughout environmental demands when differentiated by GPR and land use typologies. This is an important consideration, as GPR and land use can affect mobility performance in urban environments, especially for older adults with cognitive impairment. Interestingly, the CI group had a higher average DGS in residential and community areas and a lower DGS in business and commercial areas. This highlights the need to understand the interactions of community activities and participation related to social and economic factors that could affect mobility. In addition, the case study on heatmapping based on DGS also provided visualization that environmental familiarity may affect gait speed, particularly for those with CI. The limitations of the study were the small sample size and the observational description of 2 participants on the heatmap. However, the participants were tracked daily and continuously for 7 days to ensure that their mobility was captured as a habitual daily activity. Future research on a larger sample with additional environmental, social, and even climate factors and a longitudinal follow-up will enable a richer understanding of ageing and cognitive impairment with their environment.

Abbreviations

DGS
Daily Life Gait Speed
GPS
Global Positioning System
km/h
Kilometre per hour
m/s
Meter per second
URA
Urban Redevelopment Authority

Declarations

Competing interests

The authors declare that they have no competing interests.

Availability of Data and Materials

The data that support the findings of this study are available from Ageing Research Institute for Society and Education (ARISE), Nanyang Technological University (NTU), but restrictions apply to the availability of these data, which were used under licence for the current study and so are not publicly available. The data are, however, available from the authors upon reasonable request and with the permission of Ageing Research Institute for Society and Education (ARISE), Nanyang Technological University (NTU).

Human Ethics and Consent to Participate:

This study was approved by the National Healthcare Group's Domain Specific Review Board (NHG DSRB Ref: 2017/00937). The DSRB's research policies are based on local and international ethical guidelines, including the Belmont Report, Declaration of Helsinki, and Ministry of Health Singapore Code of Ethical Practice in Human Biomedical Research. Written informed consent was obtained from all participants before enrolment into the study. This method of informed consent was approved by the ethics committee.

Funding

This material is based on research/work supported by Singapore's Ministry of National Development and National Research Foundation under the Land and Liveability National Innovation Challenge Funding Programme (grant number L2NICTDF1–2017-2). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not reflect the views of Singapore's Ministry of National Development, National Research Foundation or any of the agency

collaborators. The grant funders were not involved in the design of the study, the collection, analysis and interpretation of data, or the writing of the manuscript.

References

1. Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychol Sci*, *19*(12), 1207-1212. https://doi.org/10.1111/j.1467-9280.2008.02225.x
2. Bohannon, R. W., & Williams Andrews, A. (2011). Normal walking speed: a descriptive meta-analysis. *Physiotherapy*, *97*(3), 182-189. https://doi.org/https://doi.org/10.1016/j.physio.2010.12.004
3. Bornstein, M. H., & Bornstein, H. G. (1976). The pace of life. *Nature*, *259*(5544), 557-559. https://doi.org/10.1038/259557a0
4. Cheng, V. (2009). Understanding Density and High Density.
5. Cho, G.-H., & Rodriguez, D. (2015). Location or design? Associations between neighbourhood location, built environment and walking. *Urban Studies*, *52*(8), 1434-1453. https://www.jstor.org/stable/26146064
6. Chung, J., Boyle, J., & Wheeler, D. C. (2022). Relationship Between Life-Space Mobility and Health Characteristics in Older Adults Using Global Positioning System Watches. *J Appl Gerontol*, *41*(4), 1186-1195. https://doi.org/10.1177/07334648211054834
7. Chung, J., Sargent, L., Brown, R., Gendron, T., & Wheeler, D. (2021). GPS Tracking Technologies to Measure Mobility-Related Behaviors in Community-Dwelling Older Adults: A Systematic Review. *J Appl Gerontol*, *40*(5), 547-557. https://doi.org/10.1177/0733464820979801
8. Crane, B. M., Moored, K. D., Rosso, A. L., & Carlson, M. C. (2022). Using GPS Technologies to Examine Community Mobility in Older Adults. *J Gerontol A Biol Sci Med Sci*. https://doi.org/10.1093/gerona/glac185
9. Del Pozo Cruz, B., Ahmadi, M., Naismith, S. L., & Stamatakis, E. (2022). Association of Daily Step Count and Intensity With Incident Dementia in 78 430 Adults Living in the UK. *JAMA Neurol*, *79*(10), 1059-1063. https://doi.org/10.1001/jamaneurol.2022.2672
10. Fratiglioni, L., Wang, H. X., Ericsson, K., Maytan, M., & Winblad, B. (2000). Influence of social network on occurrence of dementia: a community-based longitudinal study. *Lancet*, *355*(9212), 1315-1319. https://doi.org/10.1016/s0140-6736(00)02113-9
11. Gatto, N. M., Henderson, V. W., Hodis, H. N., St John, J. A., Lurmann, F., Chen, J. C., & Mack, W. J. (2014). Components of air pollution and cognitive function in middle-aged and older adults in Los Angeles. *Neurotoxicology*, *40*, 1-7. https://doi.org/10.1016/j.neuro.2013.09.004
12. Giles-Corti, B., Vernez-Moudon, A., Reis, R., Turrell, G., Dannenberg, A. L., Badland, H., Foster, S., Lowe, M., Sallis, J. F., Stevenson, M., & Owen, N. (2016). City planning and population health: a global challenge. *Lancet*, *388*(10062), 2912-2924. https://doi.org/10.1016/s0140-6736(16)30066-6
13. Hausdorff, J. M., Schweiger, A., Herman, T., Yogev-Seligmann, G., & Giladi, N. (2008). Dual-task decrements in gait: contributing factors among healthy older adults. *J Gerontol A Biol Sci Med Sci*,

63(12), 1335-1343. https://doi.org/10.1093/gerona/63.12.1335

14. Ho, S. H., Tan, D. P. S., Tan, P. J., Ng, K. W., Lim, Z. Z. B., Ng, I. H. L., Wong, L. H., Ginting, M. L., Yuen, B., Mallya, U. J., Chong, M. S., & Wong, C. H. (2020). The development and validation of a prototype mobility tracker for assessing the life space mobility and activity participation of older adults. *BMC Geriatr*, *20*(1), 251. https://doi.org/10.1186/s12877-020-01649-x
15. Kaspar, R., Oswald, F., Wahl, H. W., Voss, E., & Wettstein, M. (2015). Daily mood and out-of-home mobility in older adults: does cognitive impairment matter? *J Appl Gerontol*, *34*(1), 26-47. https://doi.org/10.1177/0733464812466290
16. Kawai, H., Obuchi, S., Hirayama, R., Watanabe, Y., Hirano, H., Fujiwara, Y., Ihara, K., Kim, H., Kobayashi, Y., Mochimaru, M., Tsushima, E., & Nakamura, K. (2021). Intraday variation in daily outdoor walking speed among community-dwelling older adults. *BMC Geriatr*, *21*(1), 417. https://doi.org/10.1186/s12877-021-02349-w
17. Kirkcaldy, B., Furnham, A., & Levine, R. (2001). Attitudinal and personality correlates of a nation's pace of life. *Journal of Managerial Psychology*, *16*(1), 20-34. https://doi.org/10.1108/02683940110366551
18. Lamoth, C. J., van Deudekom, F. J., van Campen, J. P., Appels, B. A., de Vries, O. J., & Pijnappels, M. (2011). Gait stability and variability measures show effects of impaired cognition and dual tasking in frail people. *Journal of Neuroengineering and Rehabilitation*, *8*(1), 2. https://doi.org/10.1186/1743-0003-8-2
19. Lane, A. P., Hou, Y., Hooi Wong, C., & Yuen, B. (2020). Cross-sectional associations of neighborhood third places with social health among community-dwelling older adults. *Soc Sci Med*, *258*, 113057. https://doi.org/10.1016/j.socscimed.2020.113057
20. Lu, Y., Sarkar, C., & Xiao, Y. (2018). The effect of street-level greenery on walking behavior: Evidence from Hong Kong. *Social Science & Medicine*, *208*, 41-49. https://doi.org/https://doi.org/10.1016/j.socscimed.2018.05.022
21. Margot-Cattin, I., Kühne, N., Öhman, A., Brorsson, A., & Nygard, L. (2021). Familiarity and participation outside home for persons living with dementia. *Dementia*, *20*(7), 2526-2541. https://doi.org/10.1177/14713012211002030
22. Menz, S., Rassia, S., Jiang, Y., Kumar, A., Bastianello, D., Glaser, M. A., & Graham, C. C. (2014). *Public space Evolution in High-density Living in Singapore. Ground and Elevated Public Spaces in Public Housing Precincts*. Future Cities Laboratory, ETH Singapore SEC Ltd. https://doi.org/10.3929/ethz-a-010583367
23. Ngandu, T., Lehtisalo, J., Solomon, A., Levälahti, E., Ahtiluoto, S., Antikainen, R., Bäckman, L., Hänninen, T., Jula, A., Laatikainen, T., Lindström, J., Mangialasche, F., Paajanen, T., Pajala, S., Peltonen, M., Rauramaa, R., Stigsdotter-Neely, A., Strandberg, T., Tuomilehto, J., . . . Kivipelto, M. (2015). A 2 year multidomain intervention of diet, exercise, cognitive training, and vascular risk monitoring versus control to prevent cognitive decline in at-risk elderly people (FINGER): a

randomized controlled trial. *Lancet*, *385*(9984), 2255-2263. https://doi.org/10.1016/s0140-6736(15)60461-5

24. Oliver, L. N., Schuurman, N., & Hall, A. W. (2007). Comparing circular and network buffers to examine the influence of land use on walking for leisure and errands. *International Journal of Health Geographics*, *6*(1), 41. https://doi.org/10.1186/1476-072X-6-41
25. Power, M. C., Weisskopf, M. G., Alexeeff, S. E., Coull, B. A., Spiro, A., 3rd, & Schwartz, J. (2011). Traffic-related air pollution and cognitive function in a cohort of older men. *Environ Health Perspect*, *119*(5), 682-687. https://doi.org/10.1289/ehp.1002767
26. Schimpl, M., Moore, C., Lederer, C., Neuhaus, A., Sambrook, J., Danesh, J., Ouwehand, W., & Daumer, M. (2011). Association between Walking Speed and Age in Healthy, Free-Living Individuals Using Mobile Accelerometry—A Cross-Sectional Study. *PLoS One*, *6*(8), e23299. https://doi.org/10.1371/journal.pone.0023299
27. Seeman, T. E., Lusignolo, T. M., Albert, M., & Berkman, L. (2001). Social relationships, social support, and patterns of cognitive aging in healthy, high-functioning older adults: MacArthur studies of successful aging. *Health Psychol*, *20*(4), 243-255. https://doi.org/10.1037//0278-6133.20.4.243
28. Seo, K., Takayanagi, N., Sudo, M., Yamashiro, Y., Chiba, I., Makino, K., Lee, S., Niki, Y., & Shimada, H. (2023). Association between daily gait speed patterns and cognitive impairment in community-dwelling older adults. *Scientific Reports*, *13*(1), 2783. https://doi.org/10.1038/s41598-023-29805-4
29. Shoval, N., Wahl, H.-W., Auslander, G., Isaacson, M., Oswald, F., Edry, T., Landau, R., & Heinik, J. (2011). Use of the global positioning system to measure the out-of-home mobility of older adults with differing cognitive functioning. *Ageing & Society*, *31*(5), 849-869. https://doi.org/10.1017/S0144686X10001455
30. Tudor-Locke, C., Craig, C. L., Aoyagi, Y., Bell, R. C., Croteau, K. A., De Bourdeaudhuij, I., Ewald, B., Gardner, A. W., Hatano, Y., Lutes, L. D., Matsudo, S. M., Ramirez-Marrero, F. A., Rogers, L. Q., Rowe, D. A., Schmidt, M. D., Tully, M. A., & Blair, S. N. (2011). How many steps/day are enough? For older adults and special populations. *Int J Behav Nutr Phys Act*, *8*, 80. https://doi.org/10.1186/1479-5868-8-80
31. URA. (2019). *The planning act master plan written statement 2019*. https://www.ura.gov.sg/-/media/Corporate/Planning/Master-Plan/MP19writtenstatement.pdf
32. URA. (2023). *URA SPACE: Planning data for building professionals, business operators and public*. https://www.ura.gov.sg/maps/
33. Van Cauwenberg, J., Van Holle, V., Simons, D., Deridder, R., Clarys, P., Goubert, L., Nasar, J., Salmon, J., De Bourdeaudhuij, I., & Deforche, B. (2012). Environmental factors influencing older adults’ walking for transportation: a study using walk-along interviews. *International Journal of Behavioral Nutrition and Physical Activity*, *9*(1), 85. https://doi.org/10.1186/1479-5868-9-85
34. Vasilikou, C., & Nikolopoulou, M. (2020). Outdoor thermal comfort for pedestrians in movement: thermal walks in complex urban morphology. *International Journal of Biometeorology*, *64*(2), 277-291. https://doi.org/10.1007/s00484-019-01782-2

35. Walmsley, D. J., & Lewis, G. J. (1989). The Pace of Pedestrian Flows in Cities. *Environment and Behavior*, *21*(2), 123-150. https://doi.org/10.1177/0013916589212001
36. Warren, M., Ganley, K. J., & Pohl, P. S. (2016). The association between social participation and lower extremity muscle strength, balance, and gait speed in US adults. *Prev Med Rep*, *4*, 142-147. https://doi.org/10.1016/j.pmedr.2016.06.005
37. Wettstein, M., Wahl, H.-W., Shoval, N., Auslander, G., Oswald, F., & Heinik, J. (2015). Identifying Mobility Types in Cognitively Heterogeneous Older Adults Based on GPS-Tracking:What Discriminates Best? *Journal of Applied Gerontology*, *34*(8), 1001-1027. https://doi.org/10.1177/0733464813512897
38. Weuve, J., Puett, R. C., Schwartz, J., Yanosky, J. D., Laden, F., & Grodstein, F. (2012). Exposure to particulate air pollution and cognitive decline in older women. *Arch Intern Med*, *172*(3), 219-227. https://doi.org/10.1001/archinternmed.2011.683
39. Wu, J., Wilhelm, M., Chung, J., & Ritz, B. (2011). Comparing exposure assessment methods for traffic-related air pollution in an adverse pregnancy outcome study. *Environ Res*, *111*(5), 685-692. https://doi.org/10.1016/j.envres.2011.03.008
40. Yesiltepe, D., Conroy Dalton, R., & Ozbil Torun, A. (2021). Landmarks in wayfinding: a review of the literature. *Cognitive processing*, *22*(3), 369-410. https://doi.org/10.1007/s10339-021-01012-x
41. Yin, L., Raja, S., Li, X., Lai, Y., Epstein, L., & Roemmich, J. (2013). Neighbourhood for Playing: Using GPS, GIS and Accelerometry to Delineate Areas within which Youth are Physically Active. *Urban Studies*, *50*(14), 2922-2939. https://doi.org/10.1177/0042098013482510
42. Yu, R., Cheung, O., Lau, K., & Woo, J. (2017). Associations between Perceived Neighborhood Walkability and Walking Time, Wellbeing, and Loneliness in Community-Dwelling Older Chinese People in Hong Kong. *Int J Environ Res Public Health*, *14*(10). https://doi.org/10.3390/ijerph14101199
43. Zarghami, E., Karimimoshaver, M., Ghanbaran, A., & SaadatiVaghar, P. (2019). Assessing the oppressive impact of the form of tall buildings on citizens: Height, width, and height-to-width ratio. *Environmental Impact Assessment Review*, *79*, 106287. https://doi.org/https://doi.org/10.1016/j.eiar.2019.106287

Footnotes

1. URA Website: https://www.ura.gov.sg/maps/. You can look up the maximum allowed height for buildings in certain plots using the search bar. Simply input the address or name or click an area on the map, and then click on ‘Redevelop Site’ and you’ll be able to see the maximum height of the building.

Figures

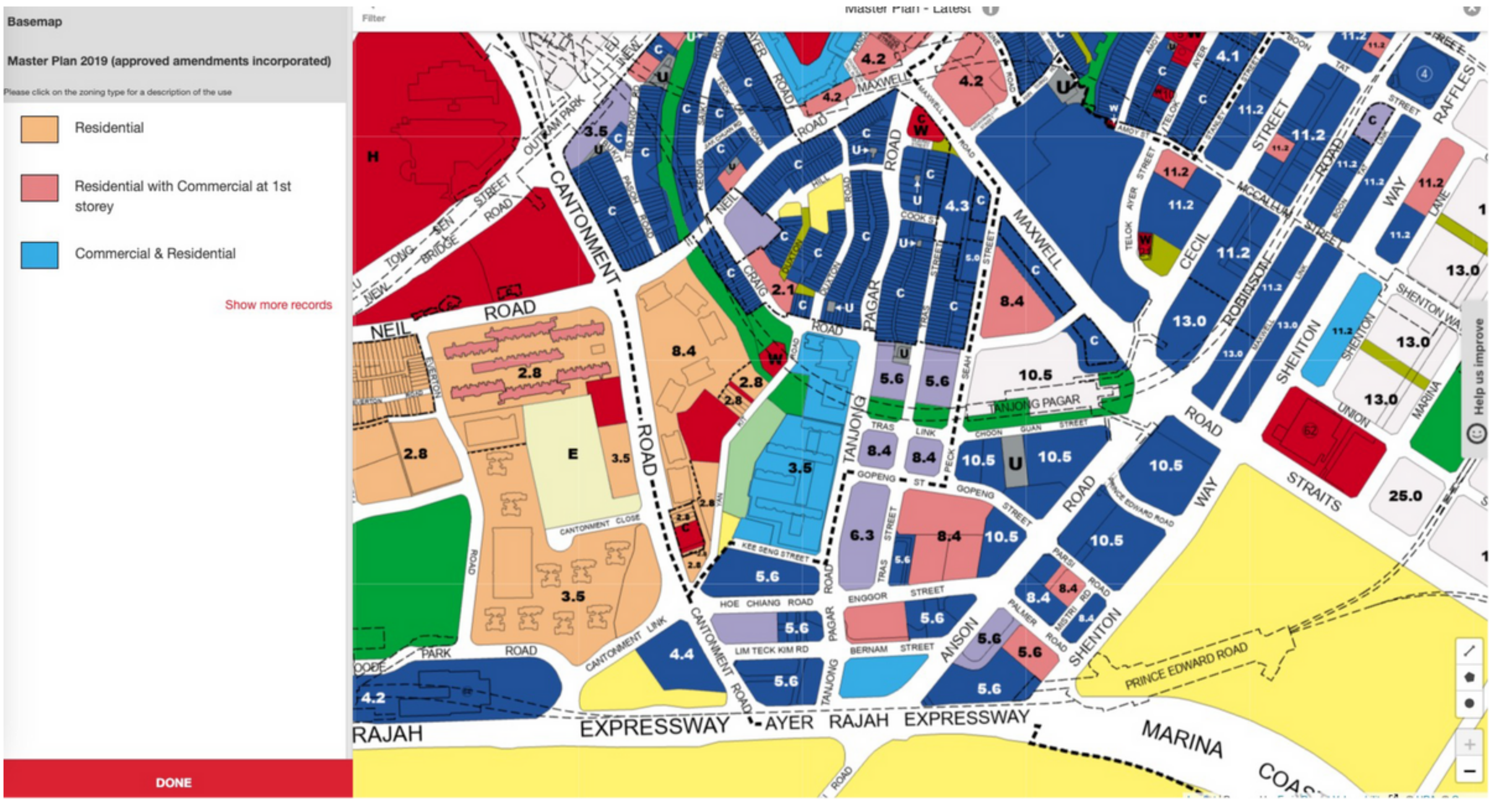

Figure 1

URA's online masterplan map with Gross Plot Ratio and Land Use (URA, 2023).

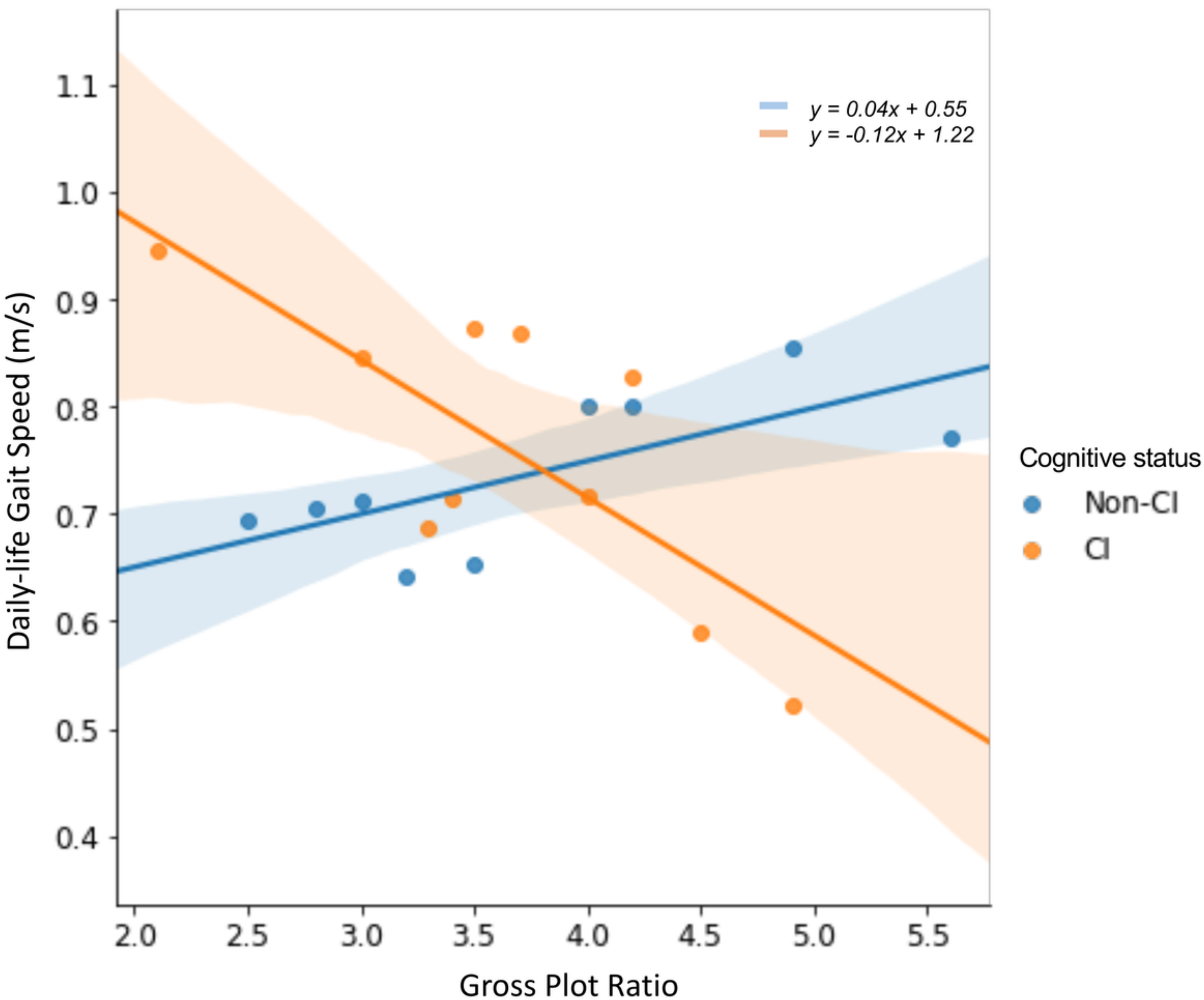

Figure 2

Daily Life Gait Speed (DGS) (m/s) by Gross Plot Ratio.

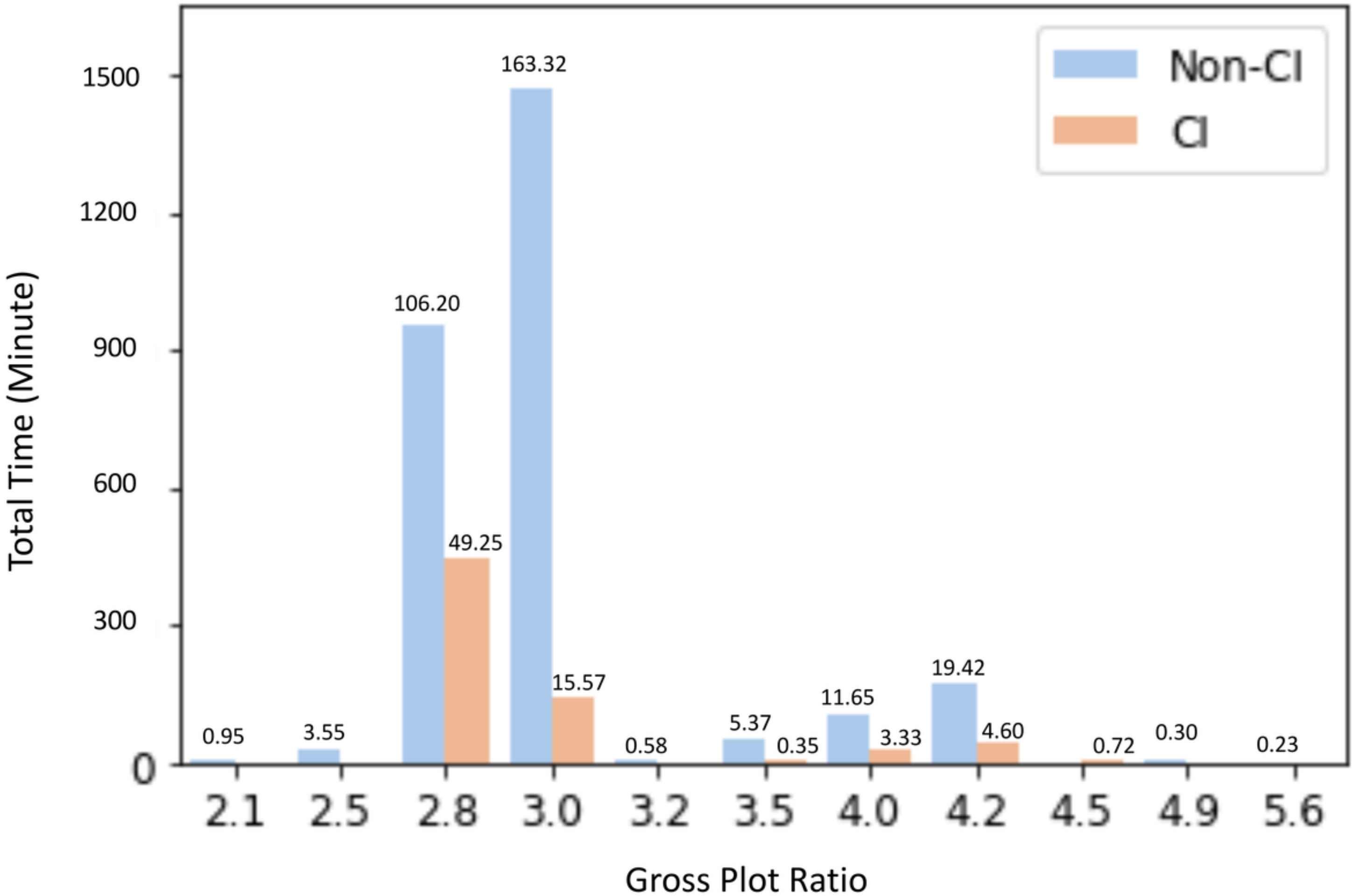

Figure 3

Total Time Spent (Minutes) across Gross Plot Ratio.

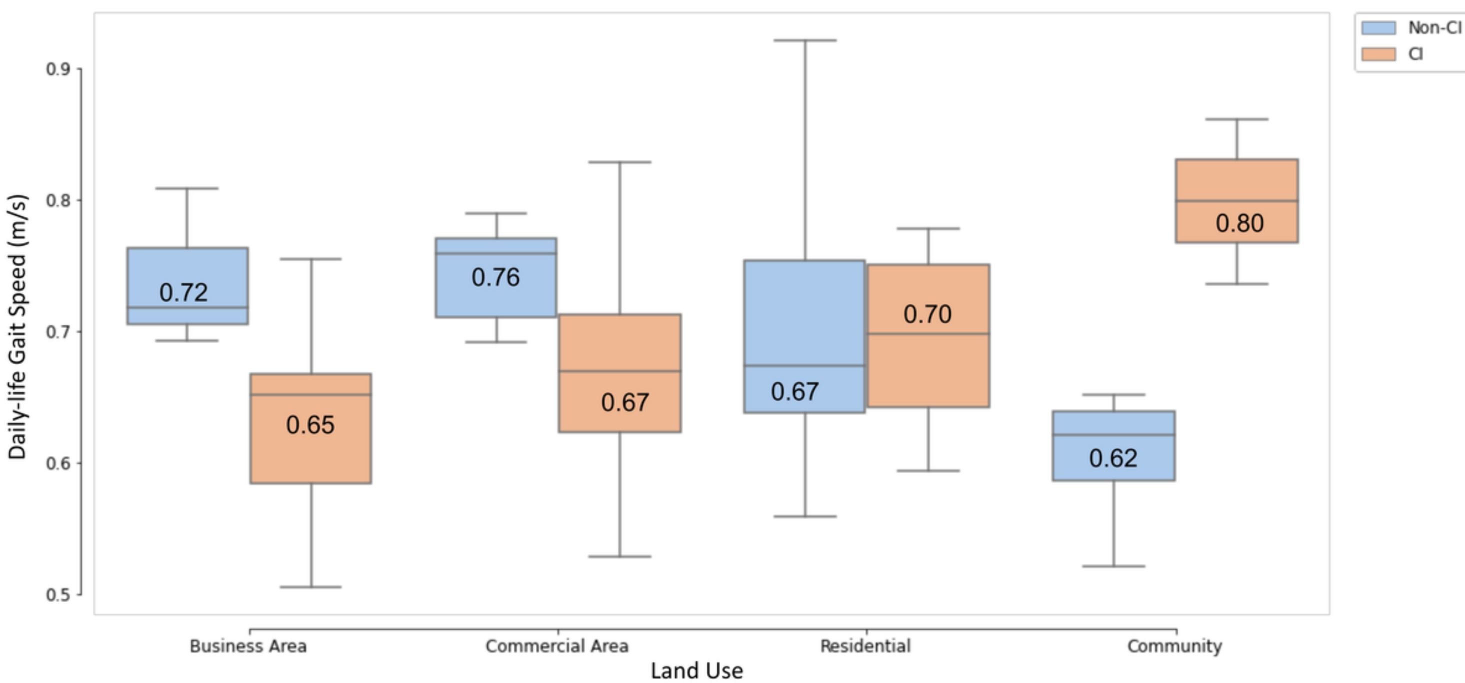

Figure 4

Daily Life Gait Speed (DGS) (m/s) by Land Use.

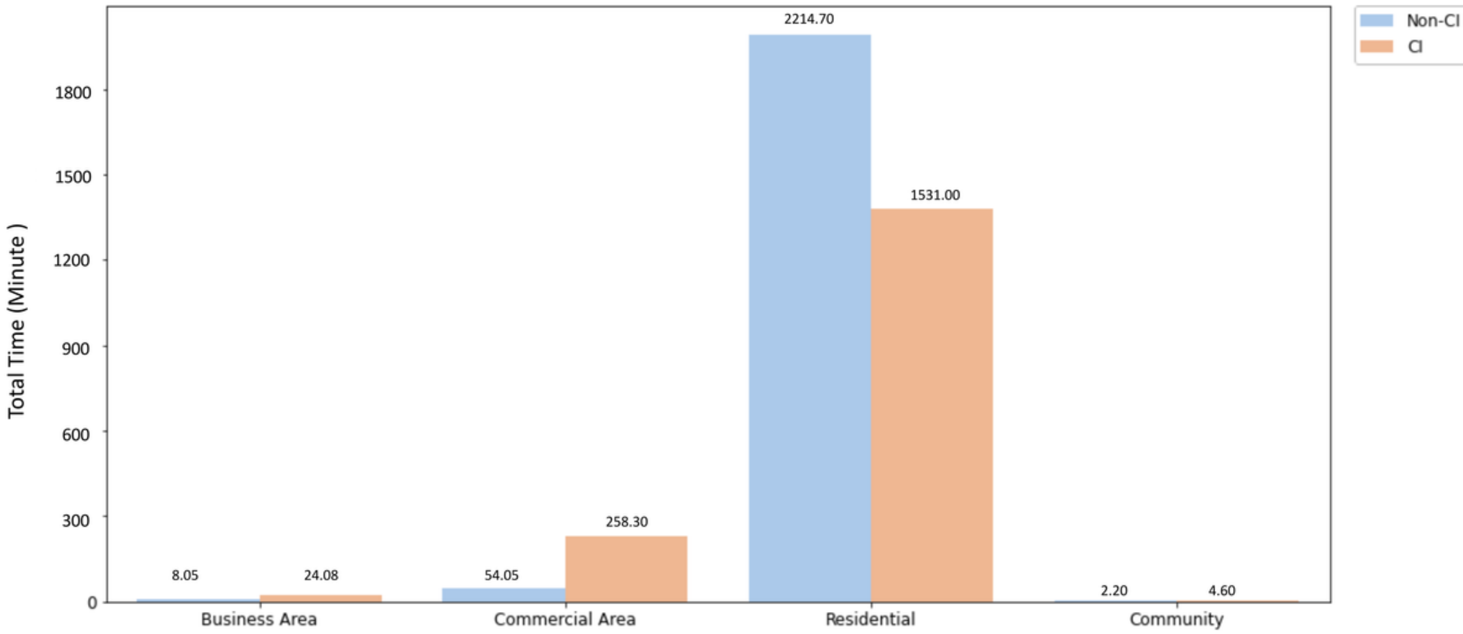

Figure 5

Total time spent (by minute) across land use types.

Figure 6

Daily outdoor trajectory comparison of two cases (CI and non-CI) living in the same area (colour represents the daily life gait speed; blue represents low speed and red represents high speed, average DGS is 0.74 m/s).