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Does the level of transportation service affect the disparity of activity opportunities between localities ?

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Abstract

It is a question whether there exist disparities in opportunities for activities of daily living (ADL) between community-dwelling people in suburban areas with low transport service levels and those in urban areas with high levels. This study investigates whether any such disparities depend on the level of transport service. We choose food shopping as an example, and use "95th percentile frequency of shopping" as a proxy for shopping opportunities and a proposed "accessibility index" as a proxy for transport service level, using data from surveys regarding travel patterns and living conditions. The results show that (1) the mean value of the accessibility index is positively correlated with the 95th percentile frequency of shopping, indicating that reductions in activity opportunities are correlated to a decreased transport service level, and that (2) for those less capable of going outdoors (ADL score is lower than 11), a low accessibility level tends to reduce opportunities for shopping

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1. Introduction

People must be able to perform basic activities, such as buying food, receiving medical services, withdrawing cash, and socialising with friends, whenever they want to. Securing opportunities for various activities is vital in order to

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enjoy the comforts of daily life. However, the extent of activity opportunities may differ by geographic area. For example, there may be differences in the activity opportunities among those in suburban areas with low transport service levels and those in urban areas with high levels.

This study aims to clarify whether disparities in activity opportunities exist in a typical regional area of Japan between suburban and urban areas, and to analyse whether any such disparities depend on transport service levels. As one of several transport service levels, we focus on ease of access to activity facilities from dwellings, and as one of several basic activities, we focus on grocery shopping. We analyse these using "95th percentile frequency of shopping" as a proxy for shopping opportunities and an "accessibility index" as a proxy for transport service level, using data from questionnaire surveys about travel patterns (so-called "person trips") and current living conditions in the target area.

We evaluate opportunities for shopping activities according to the frequency of the activity. This means that we define the degree of the activity opportunity as the level of potential or feasible opportunity for shopping activities. Following Sen's capability approach, functioning means the level of realised welfare, and capability means the level of potential or feasible welfare (Sen, 1985; Kuklys, 2005; Robeyns, 2005). In this research, we define activity opportunity as synonymous with capability.

2. Definition

We define an opportunity for activity as a potential or feasible opportunity, not a realised opportunity. Opportunities are subsequently classified as feasible or realised.

Let $\mathbf{A}$ and $\mathbf{B}$ be the sets of feasible and $\overline{\mathbf{B}} = \mathbf{A} - \mathbf{B}$) feasible activities. The set of opportunities that a person has not realised, $\mathbf{A} \cap \overline{\mathbf{B}}$, contains the set of recognised but not realised opportunities, $\mathbf{C} \cap \overline{\mathbf{B}}$, and the set of the opportunities that a person could not realise due to not recognising them, $\mathbf{A} \cap \mathbf{C}$.

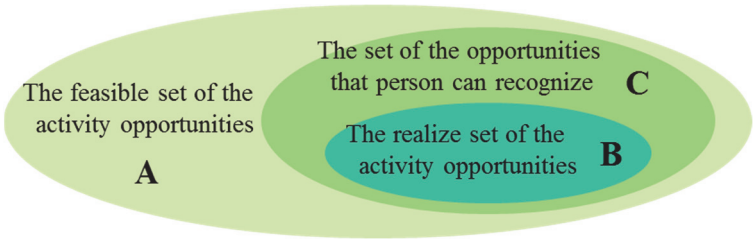

Fig. 1. Definitions of activity opportunities.

3. Study Review

3.1. Studies on activities of daily living

There are many studies that focus on realised activities of daily living (ADL). For example, Miyazaki et al. (2005) investigated the frequency of going outdoors among community-dwelling older adults in a rural area of Japan, and showed that car use and the level of public transport services influence the frequency of going outdoors. Hashimoto and Tao (2014) showed that the ability to go outdoors, travel time to activity facilities, age, and gender influence the frequency of going outdoors for community-dwelling older adults.

It is unclear whether factors obtained from these analyses influence activity opportunities.

3.2. Studies on the measurement of activity opportunies

There are fewer studies concerning measurement of activity opportunities. Nitta and Takebayashi (2010) evaluated influence factors for physical activity and social participation relating to travel behaviour through the multidimensional welfare approach, and presented car use, walking distance, and the location of activity facilities as strong influencing factors. However, they did not show a relation between these factors and specific levels of transport services. Moriyama et al. (2002) investigated the relation between transport service level and quality of life for community-dwelling older adults, and showed that enhanced accessibility eased physical performance. However, this assessment was in terms of utility, not capability. While these studies suggest that the transport service level may influence activity 3.3. Sopportunities, they lack findings about any mathematical relationship between them.

3.3. Studies on accessibility measurement

Many studies have investigated accessibility based on travel behaviour, especially transport studies in civil engineering. Tanimoto et al. (2009) focused on limitations imposed on personal activity patterns by fixed routes and fixed schedules for rural public transport services, and proposed an accessibility index based on enumerating the patterns of feasible time-resource allocations under a given service level. However, these are premised on everyone's use of routes and schedules. In reality, physical ability and feasible time for going outdoors also limit personal activity patterns. Kita et al. (2012) extended usability of the accessibility index proposed by Tanimoto et al. (2009) to consider these limitations. Kita et al. (2015) proposed an accessibility index that considers various limitations on activity opportunities, such time schedules of transport service, the burden of walking from dwellings to stations, hours of operation of activity facilities, and feasible times for going outdoors. This research found a correlation between the proposed accessibility index and the frequency of shopping activity as a proxy for activity opportunity.

4. Methods

4.1. Analysis procedure

In our analysis, various factors influencing opportunities for shopping activity, except the transport service level, are statistically controlled. We classify samples obtained from surveys along the same lines and then conduct regression analysis that sets the activity opportunity as an objective and the level of service as explanatory variables, respectively.

4.2. Factors influencing the opportunities for shopping activity

As a result of reviewing the related research, the factors influencing the opportunities for shopping activity are believed to comprise age, sex, physical performance, car use, travel time to activity facilities, walking distance, location of activity facilities, and ability to go outdoors, in addition to the transport service level.

In all these factors, age does not directly reduce activity opportunity; age is presumed to instead be the direct cause for reduced ability to go outdoors and reduced car use. Neither is sex a direct cause, because sex differences are presumed to be reflected in the frequency of car use. When we focus on travel time to activity facilities, the factors of walking distance and location of activity facilities are integrated into the accessibility index under a given transport service level.

Accordingly, this research focuses on the ability to go outdoors, including physical performance and the accessibility index under a given transport service level as factors influencing opportunities for shopping activities.

4.3. Index of ability to go outdoors

As an index of the ability to go outdoors based on ADL (Imada, 1976), this research employs the Tokyo Metropolitan Institute of Gerontology Index of Competence (TMIG-IC) (Koyano *et al.*, 1987). The TMIG-IC is a useful measure that is widely used in Japan, because its reliability and validity have been confirmed (Koyano *et al.*, 1987; Shibata *et al.*, 2003).

In the TMIG-IC questionnaire, people answer "Yes (able to do so)" or "No (unable to do so)" to 13 ADL questions (Table 1). "Yes" answers are scored as 1 point, and "No" answers as 0 points. While cut-off values are not specified, the Japanese Ministry of Health, Labour and Welfare (MHLW) recommends considering 11 points or above as high ADL, 9–10 points as moderate ADL, and 8 points or below as low ADL. In consideration of this, we adopt ADL = 11 as the cut-off value.

Table 1. The Indices of Competence by Tokyo Metropolitan Institute of Gerontology.

	Question
1.	Can you use public transport services by yourself?
2.	Can you shop for daily necessities?
3.	Can you prepare meals by yourself?
4.	Can you pay your bills?
5.	Can you withdraw cash by yourself and handle your home banking?
6.	Can you fill out forms for your pension?
7.	Do you read newspapers?
8.	Do you read books or magazines?
9.	Are you interested in news stories or programmes dealing with health?
10.	Do you visit the homes of friends?
11.	Are you sometimes called on for advice?
12.	Are you able to visit sick friends?
13.	Do you sometimes initiate conversations with young people?

4.4. Accessibility index

We focus on grocery shopping and car use as a representative activity and mode of transport, respectively. The accessibility index proposed by Kita *et al.* (2015) evaluates a variety of time-resource allocations of shopping facility activities, in addition to ease of access to the facility.

Assume that a store is open from time $\underline{T}$ to time $\overline{T}$, and that a person driving to this store leaves home at time t_s and returns home at time t_e after finishing shopping within $[\underline{T}, \overline{T}]$. The proposed index can enumerate activity patterns from t_s to t_e, assuming a feasible combination of (t_s, t_e). A depression factor $\mathrm{e}^{-2\beta_c T_c}$, where β_c is a parameter, is incorporated into this index because physical stress tends to make the activity troublesome when one-way driving time T_c increases. Moreover, $p(t)$ is the percentage of days per week permitting going outdoors at an arbitrary time t; this is incorporated into the index because it may be limited for people living in suburban areas. The accessibility index A can be formulated as Eq. (1).

$$A = \mathrm{e}^{-2\beta_c T_c} \int_{\underline{T}}^{\overline{T}} \int_{\underline{T}}^{t_e} p(t) \mathrm{d}t_s \mathrm{d}t_e \tag{1}$$

β_c, a parameter for the depression factor, is determined according to the equivalent time coefficient method of

Mouri and Nitta (1984). When hours aboard public transport is set as 1 as a benchmark, the equivalent time coefficient of hours waiting for public transport μ_p is valued as 1.02, and the equivalent time coefficient of hours spent driving a car μ_c is valued as 1.15. In preceding research (Kita et al., 2012), the depression factor parameter β_p depending on boarding time spent using public transport was estimated as 1.814. Accordingly, β_c can be estimated by Eq. (2).

$$\beta_c = \beta_p \cdot \mu_c / \mu_p = 1.814 \times 1.15 \div 1.02 = 2.045 \tag{2}$$

4.5. Measurement of activity opportunity for buying food

When a questionnaire is conducted with regard to grocery shopping activities, one concern is that what is phrased as "groceries" in general gives respondents varying images. We use "eggs" as a specific food that is easy for respondents to have an image of and that many households consume. We choose eggs because they are inexpensive, have a short expiration date, are easy to carry, have no seasonality, and are sold everywhere.

To measure activity opportunities for buying eggs, we should measure the extent to which people can buy eggs whenever they want to. However, accurately measuring capability itself is difficult. We focus on the frequency of shopping for eggs as a proxy for this capability. Although the shopping frequency is not equivalent to the degree of capability, we can measure frequency in the following manner: (1) Group survey samples in a way almost equal to the index of the ability to go outdoors using a given mode of transport. We focus on car use as the means of transport, and allocate groups based on ADL = 11 as the cut-off value. (2) Divide each of the groups into subgroups depending on the class interval width on the accessibility index values. Let the number of class intervals and the width of class intervals be k and h, respectively. From Sturge's rule, given n total samples and an accessibility index value A, we can calculate k and h as follows:

$$k = 1 + \log_2 n, \quad h = (\max[A] - \min[A])/k \tag{3}$$

(3) For each of the subgroups within a focused group, evaluate the 95th percentile frequency of the shopping activity as a proxy for the capability of the subgroup. For an arbitrary subgroup i, let the mean of the accessibility index values and the 95th percentile frequency of the shopping activity be $\overline{A_i}$ and f_i, respectively. For a data set $(\overline{A_i}, f_i)$ for all i, we conduct regression analysis as

$$f_i = a \cdot \overline{A_i} + b + \varepsilon_i, \tag{4}$$

where a and b are parameters and ε_i is the error term. Fig. 2 and Fig.3 illustrate the above procedure.

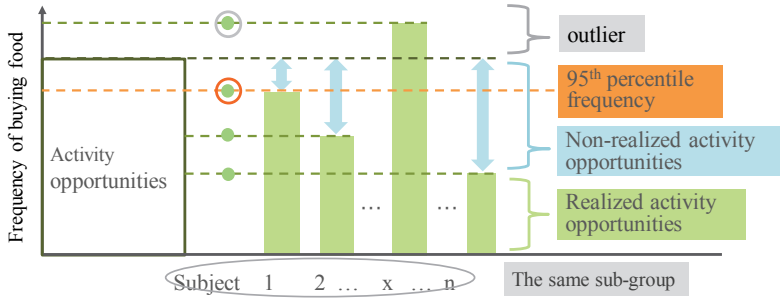

Fig.2 Relationship between 95th percentile frequency and activity opportunity

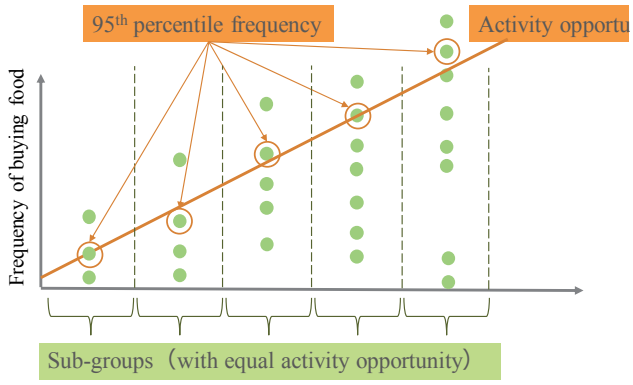

Fig.3 Relationship between the frequency of buying food and accessibility to shops.

In the procedure described above, however, we need to consider two points: firstly, in each subgroup there exists at least one person acting to maximise activity opportunities and, secondly, persons can recognize the extent to which they are capable of acting.

5. Data and Settings

5.1. Surveys for data acquisition

We conducted surveys regarding travel patterns and current living conditions in Miki City, Hyogo Prefecture, Japan. Miki, a satellite city in the Hanshin Urban Zone, lies northwest of Kobe City. As of 2014, Miki had a population of 80,000 people in 33,000 households. Miki has 10 districts. Some areas (so-called "New Towns") were newly developed after 1970, while others are sparsely inhabited with over 30% of residents being elderly.

Table 2 outlines our survey. After publicity for the survey by the Miki City Office, we conducted a travel pattern investigation (a "person trip investigation"). We then conducted a current living condition investigation on respondents who gave permission to do so in in the travel pattern investigation. Of 1,237 current living condition responses, we obtained 769 valid samples in which all questions were answered. Among these, for current living condition analysis we chose 329 individuals who reported using a car for their main mode of transport and providing a specific name of an egg-selling store.

5.2. Accessibility index values

To calculate T_c of Eq. (1), we estimate survey respondent data regarding driving time and possible days a week for going outdoors as follows. (1) Measure one-way driving hours and travel distance from home to the store using the Google Maps API. (2) Estimate driving time by dividing the travel distance obtained from the Google Maps API by an average travel speed of 35.2 km/h, following the Japanese Road Traffic Census Survey. (3) Let T_c be the one-way driving time obtained from (1) and let $\widetilde{T}_c$ be the driving time obtained from (2), estimated from regression analysis by Eq. (5).

$$T_c = 0.8265 \cdot \widetilde{T}_c + 0.0419 \tag{5}$$

We estimate $p(t)$ in Eq. (1) according to job types of survey respondents. The surveys indicated that possible

shopping times were from 8:00 am to 22:00 pm for all respondents. A working hours survey by the Japanese Trade Union Confederation showed that the average workday for regular and irregular employees in Japan is 9 h and 6.5 h, respectively. Consequently, if the job type is self-employed business, family business, or regular employee, then $p(t)$ can be expressed as follows:

$$p(t) = \begin{cases} 2/7 & \text{if } 8 \le t \le 17 \\ 1 & \text{if } 17 < t \le 22 \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

For part-time employees, $p(t)$ can be expressed as follows:

$$p(t) = \begin{cases} 1 & \text{if } 8 \le t < 9.5,\ 16 < t \le 22 \\ 1/2 & \text{if } 9.5 \le t \le 16 \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

For full-time homemakers and the unemployed, $p(t)$ can be expressed as follows:

$$p(t) = \begin{cases} 1 & \text{if } 8 \le t \le 22 \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

6. Results of Analysis

Fig. 4 and Table 3 show the analysis results for the dataset of the mean of the accessibility index values $\overline{A_i}$ and the 95th percentile frequency of the shopping activity f_i for each class interval of subgroup i. Tables 4 and 5 show the results of the regression analysis on the dataset of Fig. 2 and Table 3.

Table 2. Outline of surveys regarding both travel patterns and living conditions.

Survey region		Miki City, Hyogo Prefecture, Japan
General population		32,566 households in 2014
Sampling		Random selection method
Number of distribution		7,500 households
Method of survey		Mail-in survey
Travel pattern investigation	Date	September 7 (Sunday) and 9 (Tuesday), 2014
	Content	Age, sex, job type, mode of transport, frequency of grocery shopping activity, possible days a week for going outdoors
	Collection	5,477 individuals
Current living condition investigation	Date	November 25 (Tuesday), 2014
	Content	Frequency of shopping activity for buying eggs TMIG-IC
	Collection	1,237 individuals
Valid samples		769 individuals
Analysed samples		329 individuals

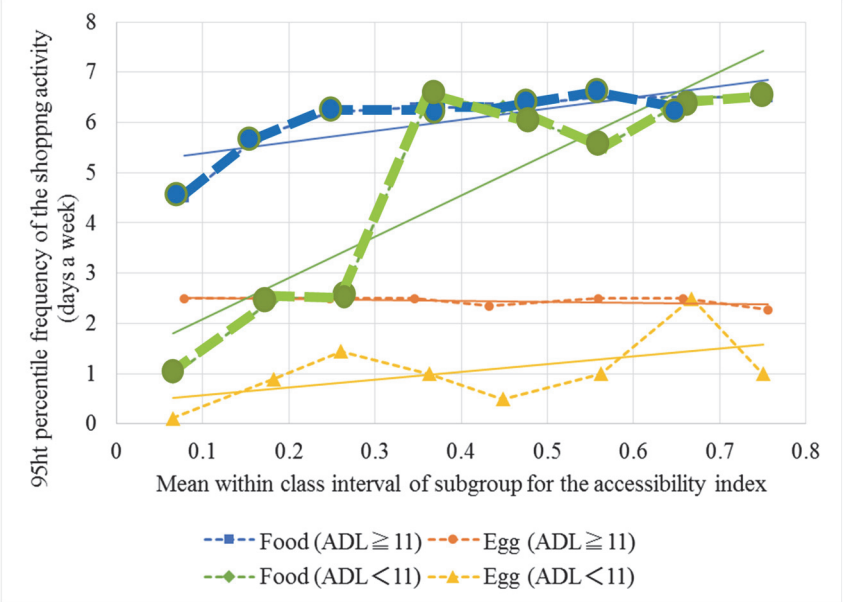

Fig. 4. The relation between $\overline{A}_i$ and f_i in Eq. (4).

Table 3. Details of the relation between $\overline{A}_i$ and f_i in Eq. (4).

Class interval of subgroup, i	ADL≥11				ADL＜11			
	$\overline{A}_i$	f_i (food)	f_i (eggs)	Sample size	$\overline{A}_i$	f_i (food)	f_i (eggs)	Sample size
0.1	0.079	4.5	2.5	11	0.065	0.95	0.12	2
0.2	0.163	5.7	2.5	29	0.183	2.5	0.9	5
0.3	0.248	6.2	2.5	64	0.261	2.5	1.45	15
0.4	0.346	6.3	2.5	43	0.363	6.5	1.0	5
0.5	0.433	6.3	2.35	23	0.448	6.3	0.5	2
0.6	0.559	6.5	2.5	37	0.562	5.5	1.0	11
0.7	0.657	6.5	2.5	41	0.668	6.5	2.5	11
0.8	0.756	6.5	2.275	24	0.750	6.5	1.0	6

Table 4. Results of the regression analysis (case of buying food in general).

	ADL≥11	ADL＜11
Parameter b (intercept) [t-value]	5.162 [15.350]	1.273 [1.359]
Parameter a (gradient) [t-value]	2.225 [3.065]*	8.205 [4.114]**
Adjusted coefficient of determination $\overline{R}^2$	0.545	0.695
Standard error	0.462	1.264
Number of samples	8	8

*: $p < 0.05$, **: $p < 0.01$.

Table 5. Results of the regression analysis (case of buying eggs).

	ADL≥11	ADL<11
Parameter b (intercept) [t-value]	2.536 [43.490]	0.414 [0.868]
Parameter a (gradient) [t-value]	–0.206 [–1.633]	1.561 [1.536]
Adjusted coefficient of determination $\overline{R}^2$	0.192	0.163
Standard error	0.080	0.644
Number of samples	8	8

*: $p < 0.05$, **: $p < 0.01$.

7. Discussion

In Table 5, values for the adjusted coefficient of determination $\overline{R}^2$ indicate a quite low correlation in the case of buying eggs. A major cause of this phenomenon may be that a shopping activity especially for buying eggs is an activity that lowers the percentage of persons who have maximised their activity opportunities. There are thus concerns that the set of feasible activity opportunities illustrated in Fig. 1 has been undervalued.

Therefore, we hereinafter focus on the case of buying food, shown in Table 4. Considering the gradients of the two regression lines for the case of buying food in Fig. 2, we can see that the transport service level for the group with low ability to go outdoors (ADL < 11) may greatly influence their activity opportunities, as compared with the group with high ability to go outdoors (an ADL greater than or equal to 11). Especially in the case of accessibility index values greater than or equal to 3.5, the shopping frequency approximately ranges from 5.5 to 6.5 days a week, regardless of differences in the ability to go outdoors. In contrast, when accessibility index values are less than 3.5, there is a notable distinction of the shopping frequencies between the two groups, depending on differences in the ability to go outdoors. Accordingly, it is evident that low accessibility levels are a serious problem for people with low ability to go outdoors.

8. Conclusion

We focused on disparities in shopping opportunities between two groups with different abilities of going outdoors depending on the transport service level. We analysed such disparities using the 95th percentile frequency of shopping as a proxy for the shopping opportunity and a proposed accessibility index as a proxy for the transport service level.

We can summarise our findings as follows: (1) The mean value of the accessibility index is positively correlated with the 95th percentile frequency of the shopping activity. That is to say, a reduction in the activity opportunity correlates to a decrease of the transport service level. (2) For those less capable of going outdoors (ADL < 11), a low accessibility level tends to reduce opportunities for realising shopping activity.

Our findings suggest that measures for enhancing the transport service level are expected to be effective for residents with low ability to go outdoors (ADL < 11) who live in localities with a low level of accessibility. Future works will address the following: (1) Although we focused on only one store where each survey respondent went to buy food (eggs), we need to consider the potential for utilising multiple stores in shopping activities. (2) Although we focused only on shopping activities, we need to analyse the relation between the transport service level and opportunities for other activities, such as receiving medical treatments or socialising with friends.

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