Willingness to walk in underground space – evidence from Singapore

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Abstract. Research on the environmental factors in promoting longer walks has focussed on the outside environment. This research concerns factors in the willingness to walk (WTW) in underground space, in a tropical climate, that of Singapore. Participants were accompanied on a pre-determined itinerary and responded to a questionnaire at intervals on perceptions of their experience and their willingness to continue walking. Several environmental factors were related to WTW. Participants ranked corridor width and the volume of pedestrians as the most important factors in comfort. Although WTW observed a distance-decay function as expected, there were restoration episodes across the participant group, strongly suggesting conditions that enable longer walks in underground space.

1. Introduction
Research on the willingness to engage in active transport, especially walking, has developed dramatically in recent years, especially with increasing concerns about public health. It is widely held, and supported by research as summarized below, that enhancements in the walking environment can have positive impacts on accumulated walking distance and walk frequency. At the same time, there is a strong move worldwide to develop underground space for a range of urban land uses, including shopping, recreation and public uses, arranged in walking environments.

The general findings in the active transport field support the proposition that outdoor environments, in particular natural settings, promote walking more than do indoor settings. As we see below, however, nearly all studies that contribute to these findings are in controlled settings and specifically in the absence of stimuli characteristic of human environments such as urban underground space. The general question addressed in this study is whether underground space can also provide a supportive environment for walking and what particular characteristics of such underground environments support the desire to walk.

This study employs the metric of ‘willingness to walk’ (WTW) as a measure of positive response to the local environment, in keeping with previous studies [1,2,3]. In theory, an environment with low levels of positive stimulus will promote a more rapid decline in willingness to walk. Environmental content, trip purpose, personal characteristics and temporal constraints may also have both negative and positive impact on WTW. In the designed environment of underground space, it is important to know how such environmental content may impact WTW.

Singapore has been exploring the potential of its underground space in recent years, freeing up the surface for residential environments, amenities and green spaces, in general improving quality of life for Singaporeans. A major plan involves developing a comprehensive pedestrian network both below and above ground in the centre of the city, where pedestrians can move around seamlessly and in all-weather comfort. The environment of this study is the extensive underground system at Orchard Road, which is the single most important concentration of shops and services in the country and operates largely in a connected system of underground concourses. Planned expansion of the underground system includes establishing connections with a new Mass Rapid Transit (MRT) line, the Thomason East Coast Line, scheduled to open to the public in stages from 2020 to 2024. As a result, the Orchard Road area will benefit from new underground concourses and interchanges in the MRT. The general question of the viability and vitality of underground systems is thus highly relevant to Singapore. The following study employs a novel method for
measuring WTW with participants actively engaging with the underground environment, as described in detail in Methods and Materials.

Following this Introduction, the paper is organized as follows: We consider firstly the literature on environmental correlates for WTW, and the revealed differences between outdoors and indoors environments. In Methods we outline our field study, the recruitment of participants and the research protocol in the real environment of Orchard Road. In Results, we report on WTW as a function of the stages in the pre-ordained itinerary and in relation to certain simultaneously recorded environmental correlates. We consider what these results mean for the layout, design and programming of underground space in Discussion. Finally, we summarize the specific results of our study in Conclusion.

2. The literature on walking stimuli

In general, it is found that the outdoors – at least those outdoor settings with natural elements and without negative environmental stressors such as heavy traffic, noise and air pollution – are more supportive of walking than are indoor environments. A large body of research has shown that exposure to the outdoors and especially natural landscape improves wellbeing. Exposure to natural settings is also associated with restoration – lowered heart rate and cardiovascular pressure, improved cognition and mental processing [4]. Exposure to the outdoors results in lowered stress levels [5]. All walking experience improves cognitive ability but walks outdoors notably contribute to restoration [6]. Overall scores for directed attention, mood and perceived exertion are improved in the outdoor exercise condition when compared with the indoor one [7]. All walking produces feelings of self-efficacy, but the effects are somewhat stronger when walking occurs outdoors [8]. These positive results for the outdoor condition over the indoor one come from studies in work environments, gyms and laboratories but do not include shopping centres or underground shopping concourses.

When we consider positive affect in indoor settings and in particular underground ones – where there is no visual access to the outdoors – a particular set of factors emerge that have some links with the findings for the outdoors, as follows. Potted plants in interior spaces raise appreciation among users of those spaces [9]. When offered the opportunity, users of interior spaces will introduce images of greenery [10]. Users of these spaces experience reductions in physical discomfort as a direct consequence of the presence of some greenery [11]. It may be concluded that greenery itself is a positive contributor to wellbeing whether or not it is associated with an outdoor and nature-like environment. Moreover, positive assessments of the environment are associated with more walking [12].

Cognitive load may be particularly significant in the underground, because of the confined space and the potential load on several senses. It is widely recognized that preference follows an inverted-U curve with respect to cognitive load although the particular dimensions have not been extensively explored. Fractal dimension (FD) is a visual measure of the complexity of the built environment. While individuals respond to FD variously, FD itself is not shown to have direct effect on micro-scale walking behaviour defined as gait, stride length or stability [13]. It may nevertheless be true that fractal dimension, along with other dimensions of cognitive load, have a mediating effect on willingness-to-walk, given the finding that environmental preference has an effect on WTW.

Comfort in interior and underground space is also a consequence of multisensory experience. Sound and illuminance may combine in environmental perception [14], and also produce both approach and flight responses. Similarly, impressions of temperature and thermal comfort are modified by the colour spectrum of light, particularly natural light filtered through roof glazing. Finishing materials produce different levels and qualities of sound, especially in combination with spatial dimensions. This soundscape is largely a consequence of people moving through the space, which also results in varying assessments among users as a direct result of the materials used [15]. It could be said that, in general, we are sensitive to the sensory environment of underground space...
and the sensations are somewhat different than those in outdoor environments. Such sensations also influence movement. For example, the stated reasons for path choice in underground space include reported visual, olfactory and auditory signals [16].

The thermal environment is more uniform in underground space than on the surface, in part as a result of geothermal characteristics and in part because of heating-ventilation-and-air-conditioning (HVAC) systems. In general, both temperature and humidity are carefully controlled to fall within the recognized human comfort zone. Such environments, even when the ambient temperature falls below conventional comfort levels, still affords control. Control alone is a major factor in satisfaction with the indoor environment [17]. Ambient temperature, wind and solar radiation all have major impact on human comfort in the outdoor environment. These factors vary as a function of street and building geometry. In tropical and semi-tropical urban environments, including Singapore, such ambient factors may be important in physiological comfort and hence in willingness-to-walk [18].

The studies discussed above also reveal the high degree of agreement among individuals with regard to their response to the ambient environment. We know less about responses to others in such settings, even though it is recognized that people expect more social interaction in interior settings [19], and the presence of others is the most important reported factor in path choice in underground space [16]. In the terms of the present investigation on WTW, we should know how people presence might have influence.

Walking trips are limited by time and energy constraints, but also by the affordances offered by the walking environment. Early studies on walking environments generally supported the distance-decay model for the frequency of walking trips – that is, a non-linear decline in numbers of trips with increasing distance [3,20]. This distance-decay function is similar to the distribution of energy expenditure as a function of distance in accumulated walking trips [2]. Travel distance in the underground environment also varies as a function of the starting point of the trip, such that layout and access to the underground system is crucially important to the amount of time spent there [21,22]. Walked distance varies as a function of trip purpose, with shopping trips being the longest of several trip purposes. Walking distance variation as a function of the physical characteristics of the walking environment and the land uses was also found in Hsu et al. [2] and in Jiang et al. [23]. It can be concluded that the distance-decay model for WTW is upheld across walking environments but is highly elastic as a function of physical environmental characteristics.

The distance-decay distribution of walking trips may also be subject to short-range reversal as a function of restoration. If all of the above ambient factors are seen to have impact on willingness-to-walk, it may be that in the course of the walk that there are restorative episodes that then result in a longer overall walk. Restoration is an important concept in health, denoting lowered blood pressure, increased attentiveness, or increased self-efficacy as markers of human health. Although not explicitly addressed in the restoration studies, it seems highly likely that restoration supports WTW. Restoration has been found to occur in exposure to natural or green environments [24], historical sites [25], positive soundscapes [26] and public squares [27], and throughout many of these studies as a function of engagement with the setting. It remains unclear, however, what aspects of the built environment result in psychological restoration. Discrete restorative experiences have been explored in controlled settings, but it remains to demonstrate how such findings generalize to the settings of everyday life. The possibility that restoration as a function of characteristics of the underground walking environment follows this important research direction but has yet to be explored. This is one of the purposes of the current study and which requires the particular methodological approach we have taken.

3. Methods
The underground network of Orchard Road complements the ground-level pedestrian space, providing direct connection to MRT stations. Orchard Road is Singapore’s premier lifestyle and shopping belt, a vibrant and exciting destination with shopping malls, hotels, offices, and amenities,
supported by a comprehensive pedestrian network both below and above ground. The network is in four quadrants, divided by Orchard Road and Paterson Road, and extended to eastern Ngee Ann City (figure 1).

The study was carried out on the main underground walkways, divided into six experimental segments, each with particular environmental character. The planned walking route starts at the first underground floor node below ION shopping mall and adjacent to Orchard station of the MRT. It continues through Wheelock Place, Shaw House, Tang Plaza, ION Orchard Link, Wisma Atria, and ends at Ngee Ann City. The entire itinerary is 860 metres in length (figure 1). Various environmental features characterize segments (figure 2), in which the respondents (n=361) conducted the survey with a structured plan, from 10 am to 8 pm, 5 to 9 January 2019.

Eleven research assistants from University of Singapore helped carry out the survey. Participants were intercepted randomly in the study environment and were also recruited through social media, including Instagram and Facebook. All respondents have resided in Singapore for more than one year, were familiar with the local areas, and were presumed to have adapted to the tropical weather. Descriptive characteristics of the respondents are summarized in Table 1. Before starting the survey, participants had a 5-minute rest period, during which they were given an overview of the detailed requirements of participation. Vouchers in the amount of S$10 were distributed to participants who completed the survey, to acknowledge their contribution.

Research assistants accompanied participants during the entire survey, with participants making evaluations of factors at the end of each walking segment. No pause or sitting was offered until the end of the survey. Firstly, they were asked to evaluate comfort with regard to seven environmental factors as follows: width of sidewalk, building feature, shade, temperature, noise, wind and numbers of pedestrians. A 7-point semantic differential scale was used for the evaluations, from extremely uncomfortable to extremely comfortable, followed by a rank ordering of the factors according to their perceived importance in walking comfort. Secondly, they evaluated willingness-to-walk from extremely unwilling to extremely willing, again with a 7-point semantic differential scale. When participants expressed a desire to quit the survey, it ended. Table 2 indicates the physical features of each segment and where they quit.

To avoid potential interactions between participants, one research assistant could accompany no more than two respondents at a time, while communication between participants was not allowed. All data were collected with smart phones using Qualtrics®, while Strava® was used to record the route and the time. Control variables included length of residency in Singapore,
residency status, visit purpose, visit frequency, exercise frequency, vigorous walking frequency, familiarity with the study environment, age and sex.

Data analyses were performed using Statistical Package for the Social Sciences (SPSS®). Distribution of responses on evaluation and ranks are reported descriptively, while bivariate correlations explored the relationship among variables. A backward linear regression for
environmental variables and control variables was conducted to tease out the specific contributions of each.

Table 1. Respondent demographics

| Variable | Our sample | DSS1 |
|----------|------------|------|
| Size of sample | 361 | 3,902,700 |
| Sex | | |
| Female | 56.2% | 50.9% |
| Male | 43.8% | 49.1% |
| Age | | |
| 15-24 | 55.1% | 13.0% |
| 25-44 | 21.1% | 30.2% |
| 45-64 | 21.1% | 29.6% |
| >65 | 2.8% | 11.7% |

Key indicators of the resident population and resident households in 2015. Department of Statistics Singapore (DSS).

Table 2. Characteristics of experimental segments

| Segment | Length (m) | Average width (m) | Average height (m) | Vertical transport | Shops/100m | Quit (%) | WTW (mean) |
|---------|------------|------------------|-------------------|-------------------|------------|----------|------------|
| 1 | 163 | 6.34 | 3.50 | - | 9.20 | - | 1.89 |
| 2 | 105 | 3.90 | 2.64 | stair, elevator | 4.76 | 6 | 1.44 |
| 3 | 135 | 5.02 | 2.78 | stair | 2.22 | 10 | 1.30 |
| 4 | 97 | 8.77 | 2.68 | stair, elevator | 12.37 | 22.2 | .97 |
| 5 | 208 | 2.50 | 2.97 | - | 12.98 | 54.0 | 1.36 |
| 6 | 152 | 4.00 | 3.16 | - | 11.84 | 13.3 | 1.00 |

4. Results

Among the seven environmental factors, number of pedestrians was the only one assessed negatively, with a mean value of -0.06 (table 3). Temperature was assessed most positively, with 63.5% of the scores distributed between 2 and 3, and the mean value at 1.62. Shade was assessed with 39.6% of the scores distributed between 2 and 3, and the mean value at 1.14. The mean values of wind, building feature, walkway width and noise were 0.76, 0.70, 0.69 and 0.12, respectively. Walkway width constitutes 30.1% of the first rank, followed by temperature at 19.8%, and number of pedestrians at 17.8%. At rank 2, the top three factors are the same as rank 1, making up respectively at 25.6%, 18.7% and 18.1%. Width of walkway has a prominent role in assessments of pedestrian comfort.

Table 3. Distributions of evaluation and ranking of environmental factors

| Factor | Comfort evaluation | Rank |
|--------|--------------------|------|
| -3 | -2 | -1 | 0 | 1 | 2 | 3 | mean | 1 | 2 |
| width | 3.0% | 9.1% | 15.2% | 10.8% | 22.7% | 28.5% | 10.5% | .69 | 30.1% | 25.6% |
| building | 0.8% | 4.4% | 8.0% | 35.5% | 19.9% | 24.7% | 6.6% | .70 | - | - |
| shade | - | 0.3% | 1.1% | 47.4% | 11.6% | 15.2% | 24.4% | 1.14 | - | - |
| temperature | - | 1.1% | 6.1% | 11.4% | 18.0% | 37.7% | 25.8% | 1.62 | - | - |
| noise | 5.3% | 10.2% | 24.1% | 15.2% | 22.2% | 18.3% | 4.7% | .12 | - | - |
| wind | - | 0.6% | 6.9% | 45.4% | 18.3% | 20.5% | 8.3% | .76 | - | - |
| pedestrian | 6.9% | 15.2% | 21.9% | 13.3% | 20.8% | 19.7% | 2.2% | .06 | 17.8% | 18.1% |

Note. -3: extremely uncomfortable; -2: moderately uncomfortable; -1: slightly uncomfortable; 0: indifferent; 1: slightly comfortable; 2: moderately comfortable; 3: extremely comfortable

Bivariate correlation analysis on the seven environmental factors indicates significant relations between pairs of factors, except the relation between numbers of pedestrians and shade or temperature. The top three Pearson correlations related to width of walkway are building feature (.536), numbers of pedestrians (.516) and noise (.367). The top three Pearson correlations related to numbers of pedestrians are noise (.613), walkway width (.516) and building feature (.281). These results strongly suggest that environmental factors operated continuously in conditioning the
evaluations. Correlations between WTW and the seven environmental factors are all significant except wind. Pearson values are in a narrow range from .114 to .246, which indicates WTW is affected broadly by environmental factors.

Linear regression with backward stepwise procedure tests the impact of environmental and control variables on evaluation of WTW (Table 4). Evaluation of WTW is linearly and positively related to walkway width, shade, frequency of engagement in sports, familiarity with the local environment, age, trip purpose that involves dining and shopping, as well as the absence of vertical transport. WTW is linearly and negatively related to noise and walked distance. Other tested variables do not interact with WTW. Orchard Road’s underground space provides an air-conditioned environment, such that the tropical weather of Singapore has little direct effect. Nevertheless, there are four significant environmental factors affecting WTW. Familiarity has a slight positive effect on WTW and longer walks. Older participants have more positive evaluations of WTW than do younger people in their twenties. Eating and shopping dominate trip purposes, affecting WTW positively and significantly.

Walked distance, related to spent energy and time, has a negative effect on WTW, while an obvious restoration of WTW occurs during the fifth experimental segment. The restoration peak (1.36) almost reaches the overall mean value of WTW (1.4) and exceeds the preceding two segments. Although the descending trend of WTW continues with walked distance on the whole, environmental stimuli delay the decline. In the fifth segment, there are all small-scale shops along the narrowest corridors in the study area (2.5m).

Table 4. Regression coefficients for factors in evaluations of WTW

| Model | Unstandardized coefficients | Std. coefficients | t | Sig. | VIF | R² | F |
|-------|-----------------------------|-------------------|---|------|-----|----|---|
|       | B                           | Std. Error        | Beta |
| 1     | (constant)                  | 1.731             | .287 | 6.025 | .000 | 243 | 10.158 |
|       | width of walkway            | .079              | .041 | .101 | 1.912 | .057 | 1.281 |
|       | noise                       | -.113             | .043 | -.141 | 2.637 | .009 | 1.310 |
|       | shade                       | .135              | .048 | .137 | 2.821 | .005 | 1.084 |
|       | how often do sports         | .181              | .049 | .195 | 3.689 | .000 | 1.114 |
|       | how familiar with here      | .128              | .073 | .087 | 1.759 | .079 | 1.283 |
|       | age                         | .176              | .072 | .124 | 2.450 | .015 | 1.175 |
|       | trip purpose-eating¹        | .841              | .212 | .204 | 3.960 | .000 | 1.217 |
|       | trip purpose-shopping       | .332              | .138 | .124 | 2.415 | .016 | 1.217 |
|       | walked distance             | -.001             | .000 | -.170 | 3.630 | .000 | 1.013 |
|       | vertical transport-none²    | .271              | .127 | .103 | 2.139 | .033 | 1.076 |

a. Dependent Variable: willingness to walk
b. ¹Reference is ‘other’ trip purpose
c. ²Reference is vertical transport-stairs

5. Discussion

The present study investigated the associations between willingness-to-walk and both physical environment and individual factors in Singapore. The hypothesis of this study is that underground environmental factors would affect the distance-decay on WTW. Previous studies demonstrating that walking distance is the most important factor affecting WTW are supported by this study. Trip purpose and individual habit on doing sports account for a big share of WTW. The perceived shade has effect on WTW, even in the underground space in Singapore, as well as noise level and width of walkway. Physical exertion on vertical transport has negative effect on WTW, especially when stairs are the only option. Restoration occurs when the environment changes, which suggests the level of WTW could be increased by controlling environmental factors, and consequently lead to a longer walking distance.
Based on stress recovery theory (SRT), postulated by Roger Ulrich [28], positive responses to natural environments will allow the individual to recover from fatigue and negative emotions. The main environmental features underlying this emotional reaction are the number of natural elements, openness, depth, moderate complexity of the setting and the absence of threats and diversionary demands. Reviewing the features of the fifth segment in this study, various shop themes, invisible ends of walkway, abundance of products and colours, relative crowdedness of items, safety and diversity of services contribute, which suggest SRT might be extended to indoor environment.

6. Conclusion
Willingness to walk in underground space is promoted by the following environmental factors: wider walkways, lower air temperature, more people, more visual stimuli in the form of window displays, higher shop density, protection from direct sunlight, and less noise. WTW is reduced by vertical movement, especially involving physical exertion.

Personal characteristics are also important in WTW. Those engaging in regular sport activities, or who walk regularly and vigorously, are more likely to respond positively to extended walking. Older people were more willing to extend their walks than were younger people. Increased familiarity with the environment also led to slighter tendency to continue the walk.

Overall, willingness-to-walk declines with distance according to the classic distance-decay function. There are nevertheless episodes of restoration in willingness, both overall in the population and among individuals. In this study, restoration was observed in parts of the underground walking space with higher levels of stimulation.

Promoting walking in the population for public health has concentrated on factors in the outdoor environment that extend walks and maintain the willingness to continue. We now observe that walks in indoor and underground environments can also be extended through the manipulation of a somewhat different set of environmental factors.

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