Research Article

The Moderating Effects of Urban Design on Willingness to Walk in a Tropical City

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Walkability and the willingness to walk (WTW) are enhanced with supportive urban design in temperate climate cities. Walking in a tropical city is challenged by the physiological stresses brought on by high air temperature, intense sunlight and humidity but it remains unknown to what extent urban design compensates for these stressors in walking behaviour. In this study, the relative impacts of the walking environment and microclimate on WTW and on walking distance were measured in a field study in Singapore. Participants executed a planned walk and reported assessments of 10 environmental factors, as well as WTW, at assigned locations. Restoration in WTW was observed at certain points on the itinerary across participants, while total voluntary walked distance equalled that of an indoor, air-conditioned walk at the same location. All environmental design variables showed a positive relationship with WTW, but not with objectively measured temperature and humidity. Urban design has a significant impact on willingness to walk in a tropical city.

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Introduction

Daily walking for able-bodied people is widely recognized as one of the best ways to counter sedentariness and incipient non-communicable disease. In general, public health programmes involving dietary change, fitness regimens, and attitudinal change have not reversed the steady and worldwide decline in fitness (UN, 2024). This human health crisis prompted the World Health Organization (WHO) initiative to reduce mortality due to obesity by one-third by 2030, as part of the United Nations' sustainable development goals (SDGs). In tropical environments it is often held that the climate does not support outdoor walks and that people resist walking in ambient conditions outside the normal comfort zone. In keeping with this notion and to provide alternative environments, urban planning promotes

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climate-controlled shopping centres and public transport, while investing little in outdoor walking environments thought to be unusable. It is widely held that these unfavourable climatic conditions prompt an approach where fitness involves a managed diet and planned physical exercise in dedicated facilities, which is very demanding anywhere in the world.

In Singapore, obesity in the population rose from 8.6% in 2013 to 10.5% in 2017, with 20.7% of the population currently at high risk (Government of Singapore, 2023). There are many initiatives to promote increased physical activity in Singapore, as well as cooling facilities in walking environments and extensive air-conditioned interior environments that are thought to host moderate physical activity like walking. The National Steps Challenge (https://www.healthhub.sg/programmes/nsc) emphasizes indoor exercise at home and at the gym, as well as organized workouts in various settings. It is widely held in Singapore that walking in a tropical climate is stressful. Various media report the long-term rise in ambient temperature in the country (Straits Times, 2023), the increasing use of air conditioning and the expansion in impermeable outdoor surfaces. In response to the increasing environmental load, the government has included in its Underground Space Master Plan, the promotion of underground tunnels for pedestrian movement. While it is often held that the use of public transport instead of the private car for commuting should increase the total amount of daily physical activity, in Singapore it was found that this belief is unsupported (Tan et al., 2018). In that study, the contribution of the walk to public transport was minor or insignificant in the total steps per day of school-age children.

It remains unclear the extent to which urban design mitigates patterns of low kinetic effort in the context of the tropical climate inducing these behavioural outcomes. If tropical climate is largely responsible for resistence to public activity outdoors, then we could expect a continuous and rapid decline in walking rates and distances across travel purposes and local, outdoor environments. If the organized physical environment were to have a dominant effect, we could expect greater variations in the observed behaviour across environments and restorations in walking distance as a function of local environmental characteristics. The present study is aimed at revealing the effects of urban design on walking outcomes in the real environment.

While many cross-sectional studies have suggested the influence of environment on self-locomotion, they cannot provide proof of causality. A quasi-experimental framework, where the environmental variables are isolated and both perceptions of walkability and observed walking behaviours are simultaneously recorded, allows us to isolate the environmental variables linked to the behaviours. Such an approach, taken in this study, also allows insights into the relationship between stated willingness to perform walking behaviour and the behaviours actually taken.

Environmental factors in willingness to walk

Positive affect is believed to support more physical activity such as walking. Exposure to an agreeable outdoor environment and especially natural landscape improves well-being. Directed attention, perceived exertion and mood are improved more substantially outdoors than indoors (Rogerson et al., 2018). All walking produces feelings of self-efficacy, but the effects are somewhat stronger when walking occurs outdoors (Weinkauff Duranso, 2019). Self-efficacy is related to feelings of control, which generally raises satisfaction with the environment. Choices within the walking environment raise the level of control. Variations in response across environments strongly suggest the differential effects of various aspects of the environment.

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 although the causal factors for the decline remain uncertain (Seneviratne, 1985; Pushkarev and Zupan, 1975). The distance-decay model for WTW is upheld across walking environments with elasticity in the distance dimension across environments. Similarity between the distributions of energy expenditure as a function of distance in accumulated walking trips and the distance-decay function (Hsu and Tsai, 2014) suggests that walking distance is at least in part limited by physical fatigue. More definite evidence of energy expenditure limitations remains scant, however.

Walking distance also varies according to the physical characteristics and land uses of the walk environment (Hsu and Tsai, 2014; Jiang et al., 2012). These positive effects of environment are widely thought to be overtaken by tropical conditions, with ambient temperature, humidity and solar radiation all thought to have major disincentivizing effects on walking (Lau et al., 2019). Direct exposure to weather stressors in a tropical environment are hard to avoid and are felt by humans in those environments, umbrellas and portable fans notwithstanding. Physiological response to tropical weather in a walk in Singapore, in the form of stress events incurred by more perspiration and a drop in skin temperature, shows great variation over the course of the walk and some consistency across the four legs of a walking exercise (Benita et al., 2020). The physiological responses to heat stressors are, however, unrelated to self-evaluations of comfort by the ten participants in that study. This result suggests that other environmental factors might be moderating the input from physiological response. In the semi-tropical environment of Hong Kong, pedestrians also experience thermal stress in certain locations and at certain times of the year, with estimates of travel time increasing with increasing stress (Jia and Wang, 2021), in keeping with previous findings. In that agent-based study with programmed responses, thermal mitigation efforts in the form of physical interventions in the street environment are largely without results on anticipated walking behaviours. In a similar way, the relatively fast pace of urban, central city walking in Singapore, compared with many temperate climate cities, is counter-intuitive in terms of human comfort (Wiseman, 2007). In general, the responses of humans to stressful thermal conditions and perceived walkability, in addition to actual behaviours in those environments, remain poorly understood.

Restoration in walking behaviour across the population signals the effect of environment. In temperate and comfortable walking conditions, the distance-decay distribution of walking trips may be subject to short-range reversal as a function of restoration (Bailey et al., 2018). Exposure to natural settings is associated with restoration – lowered heart rate and cardiovascular pressure, improved cognition and mental processing (Bowler et al., 2010). Restoration is an important concept in health, represented by lowered blood pressure, increased attentiveness, and increased self-efficacy. Exposure to the outdoors may result in lowered stress levels (Kondo et al., 2018). Restoration is found to occur in exposure to natural or green environments (Dzhambov et al., 2019), historical sites (Scopelliti et al., 2019), positive soundscapes (Aletta et al., 2018) and public squares (San Juan, 2017), and throughout many of these studies as a function of engagement with the setting.

If all of the above ambient factors are seen to have impact on WTW, it may be that in the course of the walk that there are restorative episodes followed by more walking and a cumulatively longer walk, in spite of the tropical environment. In this sense, restorative episodes promote increased WTW. Discrete restorative experiences have been explored in controlled settings, but it remains to demonstrate how such findings generalize to the settings of everyday life where conditions are felt directly, as in the present study.

How can we measure the willingness to walk and the distance actually covered by the walk? Much research on walkability has used visual imagery to gauge public willingness to walk. Extensive research has consistently shown the ecological validity of static imagery for aesthetic preference (Stamps, 1990, Hetherington et al., 1993, Heft and Nasar, 2000; Scott and Canter, 1997; Hull and Stewart, 1992; Collado et al., 2017) and for the restorative properties of environments (Ulrich et al., 1991; Collado et al., 2017). Such methods may not apply to dynamic decision-making in the course of a walk. Direct experience of the environment may introduce variations in response between built and natural environments that are not immediately perceived in static imagery (Scopelliti et al., 2019). Real world experience has many more referents than can be represented in media. In Singapore, it is found that self-reported comfort varies much more than objective measures of the local climate when participants conduct a predetermined walk itinerary (Benita et al., 2020). The environmental and physiological stressors associated with walking cannot easily be represented virtually or by enquiring on the perception of those stressors. This reality prompts the conduct of a real, planned walk with responses to environmental factors and willingness gathered throughout, the approach taken in this study.

Based on the general results of laboratory tests of walkability mentioned above, and the empirical reality of great variation in walking rates and distances across environments, we have three related hypotheses; namely, that:

1. Selected environmental factors will figure prominently in the experience of the pedestrian;
2. Grouped evaluations of the importance of those environmental factors will vary across the environment;
3. Environmental factors will play a role in the willingness to prolong walking.

The present study uses the 'willingness to walk' (WTW) metric as a measure of positive or negative response to the experienced local environment, in keeping with previous studies (Leung et al., 2018; Hsu & Tsai, 2014; Seneviratne, 1985).

Methods

Participants

Participants were invited via a social media app, where volunteers were asked to conduct an outdoor walk in the Orchard Road area, Singapore's pre-eminent shopping area, and respond to questions about their experience over the course of the walk. They could stop the walk at any time. Recruits came to the start location by public transport or car and not by non-motorized transport. There were 101 participants who completed the exercise and were compensated nominally for their time. Nearly all were Singapoean citizens, 48% were female, all had lived in Singapore more than 5 years, some for their entire lives. They were familiar or highly familiar with this well-known location, with 76% visiting the Orchard Road area at least once a month. The average age was 25 (SD=11.2).

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Location

The study of response to local conditions of a pre-assigned walk was located at Orchard Road, the pre-eminent shopping environment in the city-state, and with the highest volume-flow of pedestrians on its walking network (figure 1). The itinerary was designed to cover environmentally distinct local settings, with the whole itinerary divided into seven segments according to the major physical characteristics. The total length of the proposed walk was 2004 m (figure 2). Although there is a slight decline in elevation toward the east, the trajectory is nearly at a single level, with a maximum of a half-dozen stair steps on any one segment. All of the itinerary can be used to directly access shopping centres located on both sides of Orchard Road with some of the walk bordered by shop windows and trees. The outdoor environment of Orchard Road is relatively varied along its length, in terms of walkway width and materials, plantings, shade trees and building façades, since the outdoor treatments accompanied the development of individually initiated shopping centres. The hypothesis here is that such locally initiated landscape and building designs would be distinguishable and evaluable.

Figure 1. The outdoor walking environment on Orchard Road, Singapore.

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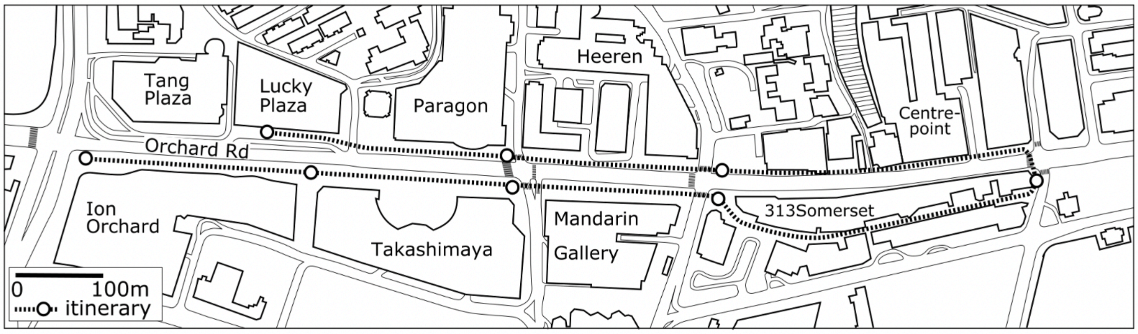

Figure 2. The Orchard Road experiment site

Method

Participants provided information on the frequency of visits to the area, their rate of participation in moderate to vigorous physical activity (MVPA) and frequency of self-assessed vigorous walking. Participants walked the first segment, at the end of which they were asked to assess the environment just traversed according to 10 items, all arranged as 7-point semantic differentials. The items were assessed for the sufficiency of provision – walkway width; pleasancy – number of pedestrians, vegetation; comfort – noise, wind, crosswalks. They then assessed their willingness to continue walking on the 7-point scale, followed by the binary continuance or termination. The assessments were repeated at the end of each subsequent segment completed by the participant and without access to the previous segment scores recorded on the research assistant's iPad. There were no rest periods or opportunities to sit although participants could progress at their own pace. Finally, the participants ranked the environmental items by importance to their experience of comfort. Distance and time information was gathered using Strava®.

Analysis

Mean WTW scores were compared across the segments of the itinerary in addition to changes in individual responses by segment. Bivariate analysis related WTW to environmental factor assessment for the related walk segment. Rank scores for factors were analyzed to gauge the importance of such environmental elements to the participant experience. Multiple regression assessed the specific contributions of environmental and design factors to WTW. A separate regression considered the contribution of visit rate, MVPA, age and sex. The following results are reported in the above order, followed by a discussion of their meaning for walkability in tropical urban environments.

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Results

Overall, 92% of participants completed four segments totalling 1041m, 48% completed five segments at 1430m, 32% completed 6 segments of 1681m, while 23% completed the circuit of 2004m. Of the 101 participants, 37 showed at least one instance of willingness restoration, 40 expressed successive decline in willingness while the remainder showed no change in WTW over the course of the walk. There is nevertheless restoration in willingness in pooled response for groups at particular junctures on the walk, with the no-restoration group starting much higher in willingness (figure 3).

There is great variation among participants in the duration of the field exercise (mean=29.3 min; sd=20.5). In theory, the longer one stands in a stressful environment, the less likely a self-assessment of comfort; however, there is no significant correlation between duration and any of the environmental factors, except a small negative effect of sunlight for longer duration walks.

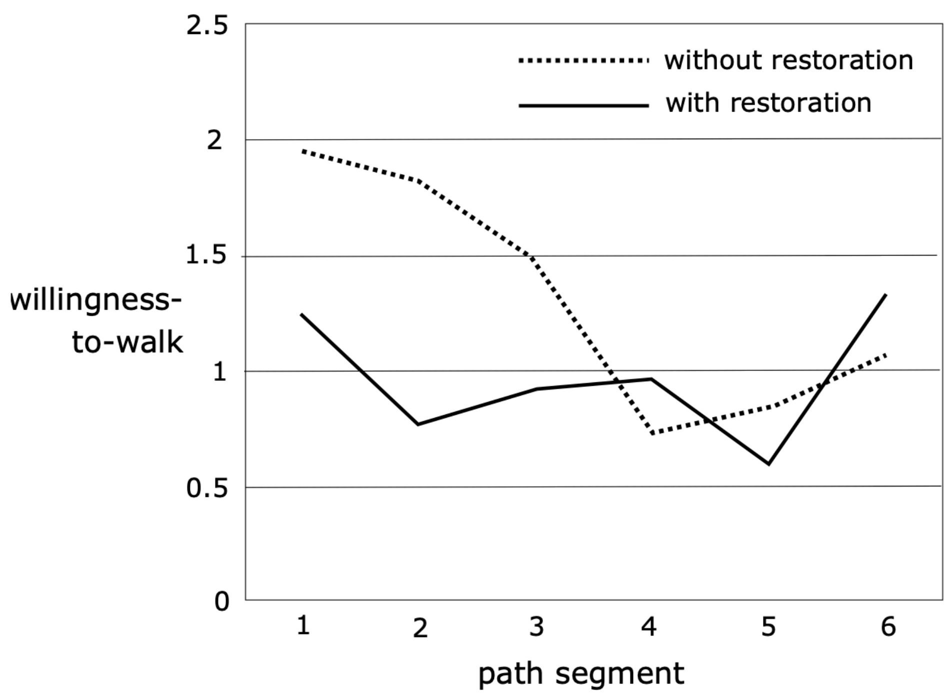

Figure 3. Mean WTW by segment by group with and without restoration in willingness over the course of the walk

There are distinct variations in response across environmental items at the first segment. Across all respondents and all items, there are four distinct levels of mean response ($p<.05$). Highest score was

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given walkway width, while vegetation levels and wind were the lowest. They were significantly lower than the comfort scores for shade and sun. Moreover, sun was given the same comfort rating as shade overall. In the second segment, again we find that shade and sunlight are in the mid-range of responses, while more negative response was given to noise, street crossing and numbers of pedestrians. In other words, the ordering and evaluation of items varied according to path segment, in keeping with our expectation that response would vary by environment.

Is there significant variation in the average response across the questions by individual? There are at least three distinct groups of participants by response level, in terms of the 95% confidence of their mean response:

- Confidence band -3 to -1 3
- Confidence band -1 to +1 27
- Confidence band +1 to +3 57

The bivariate analysis of environmental items and WTW reveal moderate to strong relations across the entire sample of walks (n=476). Willingness to continue the walk is related to walkway width (.253; p=.000); building features (.253; p=.000); shade (.066; ns); sunlight (.093; p=.042); noise (.094; p=.042); temperature (.142; p=.002); wind (.160; p=.000); street crossing (.160; p=.030); pedestrians (.207; p=.000); vegetation (.192; p=.000). Willingness may be related to comfort afforded by temperature although the result is not significant (.194) and is not related to sunlight. Over the first three segments, willingness to continue remains the same (40), decreases (36) and increases at least for one or more segments (25). Willingness is unrelated to trip duration, regardless the trip segment. WTW is unrelated to measured temperature, which was recorded in the field at the point of response, and also unrelated to humidity, retrieved from a weather report. Comfort associated with environmental factors, as assessed by participants, with the exception of shade, were positively related to WTW. These results prompted the retention of all variables in the following regression models.

We isolated the willingness question from specific evaluations such that the relationships are more likely at the subconscious level. Since the scale was a perceived comfort scale, higher values indicate higher comfort when considering a particular variable.

Regression models for environmental and human factors

For interpretability purposes, the responses to the environmental variables were separated from the control variables in the following analysis. Several tests of suitability for regression were conducted. VIF values did not exceed 1.310, eliminating any significant covariance among variables. Linearity was observed in scatter plots for all 10 independent variables. Positive correlations with WTW averaged.159 (SD=.062). The data were normally distributed, using the Shapiro-Wilk test for normality of the 10 independent variables (low=.906; high=.943; p=.000), although the Breusch-Pagan model for homoscedasticity showed marginally acceptable results (F=3.718; p=.050). The distributions across the variable set can be observed in Table 1. Overall, the tests support the entry of data into a linear regression model.

Environment	Comfort evaluation (%)							Score mean	Rank		
Factor	-3	-2	-1	0	1	2	3		1	2	3
Walkway	3.4	7.8	10.7	13.9	18.9	29.1	16.2	.893	.179	.152	.168
Façades	1.1	3.2	6.5	27.6	28.4	24.0	9.3	.882	.061	.074	.086
Shade	4.4	9.5	13.3	11.6	20.4	25.3	15.6	.722	.194	.240	.189
Sunshine	5.1	9.1	15.8	15.4	20.0	23.2	11.6	.520	.088	.173	.145
Temperature	5.3	19.8	17.5	6.9	17.5	20.0	13.1	.238	.297	.122	.038
Noise	4.2	6.1	17.5	24.8	21.1	20.8	5.5	.368	.019	.040	.057
Wind	1.7	7.2	14.7	21.9	26.7	21.1	6.7	.550	.040	.074	.080
Crossing	4.6	8.6	14.7	36.8	15.2	16.0	4.0	.133	.027	.032	.034
Pedestrians	6.9	12.2	21.1	16.2	18.9	18.3	6.3	.082	.082	.082	.065
Vegetation	2.1	3.8	10.9	31.6	24.8	20.6	6.1	.600	.011	.008	.006

Table 1. Distributions (percent) of responses by variable, mean score and rank

The size of the dataset and the effect size of individual variables prompts separate linear regressions.

Linear regression for 10 environmental factors and 475 evaluations reveals modest but significant effects for all variables with the exception of shade ($p<.05$). Individual contributions to the coefficient of determination amount to 26% of the variance (Table 2) with their combined effect amounting to 9% of variance ($F(10)=4.592$, $p=.000$), a medium effect in Cohen's (1988) terms. The strongest effects are in walkway width, building façades and in pedestrian activity. All three vary considerably on the itinerary. Walkway width varies from 6 m to 15 m. Certain buildings have shop windows, awnings, galleries and more elaborate architectural treatments while others have blind walls or simple treatments. Pedestrian volume also varies considerably over the network.

Environmental			Stand.			
Factor	R^2	B	SE	B	t	p
Walkway width	.064	.268	.060	.253	9.364	.000
Building façades	.041	.281	.078	.202	4.485	.000
Shade		ns				
Sunshine	.009	.097	.078	.093	2.040	.042
Air temperature	.009	.088	.064	.094	2.053	.041
Noise	.020	.168	.070	.142	3.128	.002
Wind	.026	.199	.068	.160	3.533	.000
Pedestrian crossing	.010	.122	.068	.100	2.177	.030
Number of pedestrians	.043	.217	.066	.207	4.608	.000
Vegetation	.037	.256	.070	.192	4.248	.000

Table 2. Regression coefficients for 10 environmental variables on WTW

To further assess the effect size of the relationship between these environmental factors and WTW, Cohen's f^2 (1988) was calculated, resulting in f^2 value of.10, a medium effect in Cohen's terms of 0.02 being a small effect and 0.35 being large in such social science research. This result should be understood in the context of a study using instantaneous assessments of multiple aspects of participants' personal experience in place.

The bivariate analysis of 9 demographic variables–years in Singapore, trip purpose, visit rate, sports activities, frequent vigorous walking, familiarity with Orchard Road, citizenship status, age and sex–with walking distance showed no significance except for sex (.231; p=.024). The linear regression for sex on walking distance reveals moderate effect at R^2=.054; F(1)=5.254; p=.024). Females walked somewhat less distance than males.

Rank of importance

Participants were asked to rank by importance the 10 variables of interest in their personal comfort at the end of each walking segment. Three ranks were allowed. Overall, there are clear preferences in importance among the variables shared by the participants. In the distributions (Table 1), it can be seen that temperature, shade and walkway width figure prominently in rank 1, while temperature declines in ranking over the next two ranks. If the ranks are weighted inversely according to rank order and cumulated, then, in order of size, are temperature, shade and walkway width. All other factors figure much less in the scoring, although all variables were ranked first by at least some individuals. The self-reported comfort scores for variables do not directly relate to the ranks of importance accorded by participants.

Intensity of the experience with regard to the elements of the environment is a good gauge of the importance of that element in eventual, supportive interventions. We take the absolute values of the assessments to represent the amplitude of the response from indifference (0). In descending order of amplitude from indifference, the factors are as follows: walkway width (1.72); sunlight (1.60); temperature (1.53); shade (1.48); pedestrians (1.47); building features (1.38); vegetation (1.37); noise (1.28); wind (1.19); street crossing (0.76). These ranks differ somewhat at the lower end from the directly assigned ranks (Table 1).

Discussion

Increasing willingness to walk lends support to the restoration theory – that something has contributed to improve their willingness to continue. The variations in experience over the course of the walk are attributable to urban design – walkway configuration and design, building façades, vegetation – along with the presence of pedestrians and noise. There remains the question whether ambient heat and humidity have nevertheless reduced the executed walk. We conducted a parallel study on the indoor, air-conditioned route at Orchard Road that is closely aligned with the outdoor environment immediately above and has approximately the same overall distance (Zacharias & Wang, 2020). The same protocols were used, with the same number of route segments and a slightly modified list of independent variables, while the participant pool was exclusive to the underground experiment. In theory, the air-conditioned indoor environment should produce a longer walk over the hot, humid and sunny outdoor environment. The two samples were arranged by the number of segments completed, with a correlation between the two sets of.97 (figure 4). Whatever the responses of the participants to the ambient conditions, the actual voluntary walk distance was nearly identical between indoor and outdoor environments in the same district.

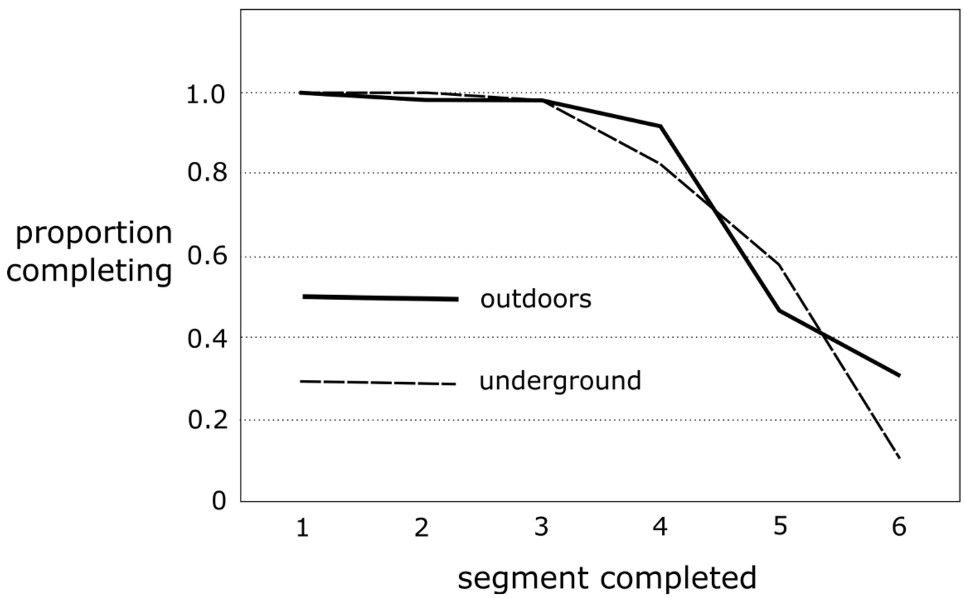

Figure 4. The distance covered by participants in the outdoor and underground exercises

The major stressors are not coming from the duration of the walk, while the actual distance traversed is likely the result of factors other than physical fatigue. Willingness itself is sufficiently related to a wide range of proximate environmental factors with no one factor dominant. Notable changes in that environment can be regarded as significant inducements for further perambulation. The increase in total traversed distance and number of steps, is achieved through specific environmental enhancements, all of

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which are attainable with environmental management in the existing physical setting, which was not specifically designed to support a comprehensive walking network.

Notwithstanding substantial agreement on local conditions, there are major differences among individuals in their walking speed and style, their use of the evaluation scale and the relation between willingness to walk further and actual continuation of the walk. Over all responses across all segments and participants, the relationship between WTW and walk continuation is positive (.35). The mean evaluation per individual was 1.48 (SD=.058), with the lowest average evaluation score at 0.70 and the highest at 2.35. In general, while participants tended to use different parts of the available scale, there was also general agreement on the relative effects of each item. This result is notable given the many possible influences on assessment, including instantaneity.

Heavy pedestrian flow might be associated with congestion or uncomfortable walking. Also, we might assume that the higher the temperature, the more uncomfortable; the noisier, the more uncomfortable. This study was concerned with the importance of the factor in WTW and its perceived effect on comfort. Hence it was possible that a relatively strong relationship between vegetation, for example, and WTW, contrasted with very low importance accorded vegetation in comfort.

The results of this study support the alternate hypothesis that climate is only one of several determinants of voluntary walking distance in a shopping district in a tropical city. Physical features of the walk environment have a preponderant role in the assessment of their individual inclination to walk further, but also in actual extensions to their walk. While the physical comfort factors were noted and had a direct relation with WTW, the cumulation of other factors had a more important role in the perceptions and subsequent behaviour.

Conclusion

Agreement among participants in their comfort assessments of environmental elements is consistent with subsequent assessment of the willingness to walk. Several elements have roughly equivalent weight in the assessments including the qualities and width of the walking surface, the visual effects of the building environment, air temperature, sunlight, environmental noise and conditions associated with the pedestrian flow. Assessments of nine factors vary positively with WTW and support a linear regression model of effects.

Participants generally agreed on the comfort effects of temperature and direct tropical sunlight but these assessments are unrelated to the simultaneously measured temperature and humidity. Clearly other factors relating to the design of the environment are interacting with these assessments of climate. Tropical climate could nevertheless remain salient in the overall outcome. To test this proposition, a parallel study of participants executing a similar walk, with the same number of test segments and distance was conducted in the climate-controlled underground environment of Orchard Road. In this way, the tropical climate was eliminated from consideration. The expected reduction in walking distance outdoors, compared with the underground route, was not upheld. Notwithstanding assessments by participants of the tropical environment, or independent measurements of those conditions, walking distance and WTW remained the same.

Participants expressed agreement on a restoration of WTW at certain junctures on the itinerary. The expected continuous decline in WTW, all other factors being equal, was not upheld in this case. As a result, it is clear that the designed environment played a role in the restoration of WTW at certain points on the itinerary. Although the results are clear, a limitation of this study is the single site with just seven environmental segments. Ideally, a set of such tropical walking settings could be studied using the same protocols, which would enable the exact measurement of the effect of certain urban design features on walking distance. In the meantime, the results of this study are relevant to planning in Singapore and specifically give hope to those advocating improvement in the outdoor environment for increased outdoor walking among Singaporeans. This result strongly supports urban design interventions with the express purpose of increasing habitual and daily walking behaviours of urbanites in a tropical city.

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Declarations

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