Cognitive Distance Affected by Urban Vegetation: Evaluation at Perspective Knowledge Level

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This research was aimed to investigate how the presence of tree lines in urban streets could affect the perspective distance judgment and to establish a set of vegetation design parameters that could affect such judgment. By varying the vegetation design parameters growth stage, spacing, tree species and canopy condition, the investigation evaluated the corresponding evaluation for the subjective distance. Results showed that subjects overestimated the distances in the vegetated settings in comparison to the non-vegetated settings. The spacing of trees was found to be affective on cognitive distance judgment.

Keywords: Cognitive distance, Perspective distance, Spatial cognition, Urban vegetation

1. Introduction

Spatial cognition is an important information source for navigational decisions. Cognitive map, having a wide acceptance as an effective representation of human spatial knowledge, is often used as a tool in evaluating spatial cognition. Through their spatial behavior people acquire important inputs leading to the formation of a new cognitive map or alterations to an existing cognitive map. Such cognitive map would in turn affects human behavior. Past researchers have extensively studied how cognitive map could be affected by the variations in spatial and geometric characteristics of the space as well as various elements therein. The need to study the effect of landscaped elements on human spatial representation has been suggested earlier[1)] considering the visual and psychological effects brought about. The use of landscaping elements to alter spatial relations of urban space is famous among designers. According to Arnold [2)] trees can organize the space in both horizontally and vertically.

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Horizontally they do it by visually enclosing, completing, or defining area of open space. Vertically they define space through the ceiling of canopy. Zube[3)] giving specific reference to tree lined streets of Paris suggested, the ability of street trees to reduce the city scale down to human comprehensible level.

Evans, Catharine, and Pezdek [4)] found that areas with landscaped elements were well represented in cognitive maps. Sheets and Manzer[5)] showed that the introduction of trees to suburban streets significantly changed the spatial cognition of subjects in a broader sense, in comparison treeless status.

The component of spatial cognition related to the distance representation is referred to as the cognitive distance. Knowledge about environmental distances is a vital source for human navigational decisions such as route, destination or mode choice.

Some literature about environmental distances considers the distance knowledge in terms of two types namely cognitive distance and perceptual distance. In this context cognitive distance refers to the human belief about distances between places in large-scale space, places which are far apart and obscured so as not to be visible from each other [6)]. The perceptual distance on the other hand refers to the people's idea about distances between places, which are visible from each other and are insight during the estimation procedure[7)]. Thus this differentiation is based on the factors whether the respondents engage in a walking task and whether the two points in between which the distance is measured could be visible at the time of distance estimation. Therefore this classification ultimately deals with how the distance is measured by the respondents. Accordingly, considering the method of evaluation of this

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experiment, which is the photo simulation method, distance investigated here falls in to the perceptual distance category. The authors however are of the view that such a classification should give more attention to what kind of distance measurement is used instead of the method of evaluation. Accordingly, any subjective distance judgment falls on to the category of cognitive distance while those distances perceivable from a single vantage point without requiring to walk for to evaluate the distance would form a special kind of the distance judgment within the group of cognitive distance called as perspective distance. Therefore those concepts applicable for cognitive distance would equally be applied to perspective distance judgment.

In an experiment to evaluate the effect of tree size and texture on judgment of tree size and distance, Serpa and Andreas[8)] found that smaller trees to be felt larger than the real size. Also the distance between the tree and the observer were overestimated in relation to the actual distance. Their results also showed fine textured trees to appear larger and more distant from the observer in relation to actual dimensions. Although their experiment was focused on direct distances from the observer to trees in a park, the results suggest the ability of trees to affect distance judgment. In addition it reminds the sensitivity of characteristics of trees such as size and texture which in a broader sense could be attributed to type of species or the growth level. The present study extends these findings by studying how the presence of vegetation in urban street could change the distance judgment in comparison to a non-vegetated setting.

Route segmentation hypothesis about distance cognition shows that, a route segmented by features would correspond to a distance judgment, which is longer than it's unsegmented form. Past researchers have used a wide range of elements such as turns, buildings as environmental features[9)]. The effect of discrete elements or groups of elements has also been discussed in previous work[10)]. Though the effect of continuous objects for distance judgments is not clear, there are some evidences that extended objects could affect allocentric representations of human's suggesting the effect on spatial cognition[11)]. Here the authors would treat street trees as the environmental feature considering its ability to be a discrete object or to form a continuous object with other trees once lined.

2. Hypotheses

2.1 Hypothesis I

Introduction of trees to the street network would not change the cognitive distances in comparison to the non-vegetated condition.

2.2 Hypothesis II

Cognitive distance judgment would not differ with the variations in design parameters governing the tree design. Variation of the design parameters tree spacing, tree species, growth stage and canopy status (summer canopy Vs winter canopy) were considered in this relation.

3. Materials and Methods

A pilot experiment was conducted to assess applicability of photos as a representative simulation of the real environment in relation to distance judgment. Distance judgements taken after real site and photo stimuli exposure revealed that they do not deviate significantly from each other. Thus the experiment the main experiment was conducted by assuming that a photo stimulus is a representative media of the real site.

The main experiment was carried out using 72 photo simulated street images as the stimuli belonging to 9 different streets. Nineteen students (14 males and 5 females) of Saitama University voluntarily participated to the experiment (Average age 26 years). The factors Growth Stage and Spacing were simulated in three levels. Species Ginko, Zelkova and Sakura (in their summer canopy condition) represented three levels of species factor along with a bare canopied condition of Zelkova tree representing the winter condition (Figure 1). Each of the resultant 36 conditions depicted a 200m long typical Japanese residential street, and was shown through two photographs to make up 72 photos. For each condition the first photo showed non-vegetated condition (reference photo) while the second one showed the vegetated (judgment photo) condition of the same street. Tree images were generated using a tree simulating software while the street images were generated using visualization software. With the use of a photo retouch software, the foresaid images were merged to produce the final stimuli depicting a viewpoint from the middle of the road.

The experiment consisted of two phases. In the first phase the non-vegetated picture condition was shown first for 10 seconds within which the participants were asked to judge the distance to a sign shown in the photo. Thereafter the judgment photo was shown for 30 seconds within which the respondents judged distances to each of the two signs in that photo and mark those distances in the evaluation sheet. The two signs represented distances belonging two objective distance ranges (range A=20m-35m; range B=50m-65m). The evaluation sheet consisted of two straight lines depicting the reference and judgment road conditions and the respondents had to mark the

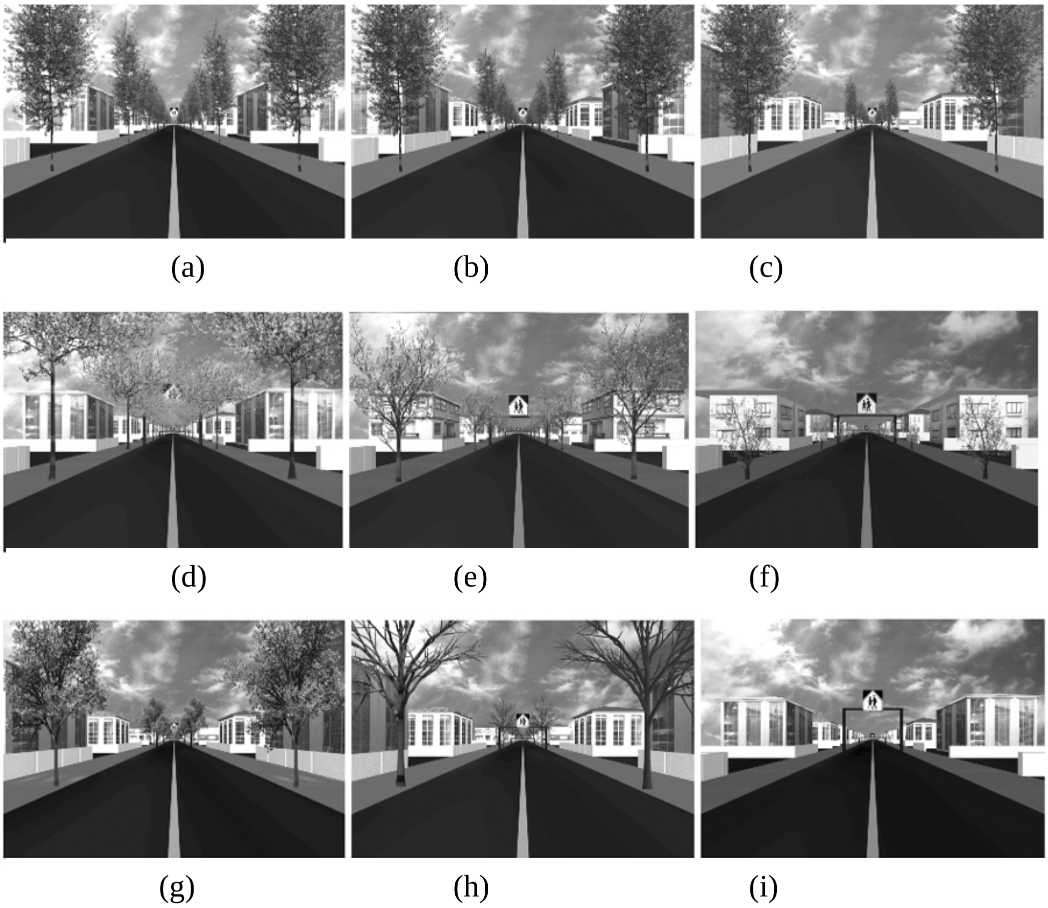

Figure. 1 :Stimuli used (a) G, G1, S1; (b) G, G1, S2; (c) G, G1, S3; (d) S, G1, S3; (e) S, G2, S3; (f) S, G3, S3; (g) Z, G1, S3; (h) W, G1, S3; (i) Reference photo (non-vegetated) condition; (G-Ginko, Z-Zelkova, W-Winter Canopy, S-Sakura; G1-Fully Grown, G2-Middle Grown, G3-Young 3; S1-10m Spacing, S2-15m Spacing, S3-30m Spacing)

judgment distances by referring to the first condition (no meter scale was provided).

The second phase was conducted to evaluate the subjects` subjective idea of distance for a given objective distance. In this phase the subjects were presented only with those pictures showing the non-vegetated condition (the same pictures as used in the phase one) of each of the 9 streets for 15 seconds. Within the given time the participants judged the distance to the sign marked on the photo in terms of meters and mark it on the evaluation sheet. The evaluation sheet had a single line on which the marking for the100m length was shown. It should be noted that the subjects were not guided with what 100m in the photo environment. Instead the 100m mark was provided in the paper to be used as a scale for marking. In each of the phases the photos were presented in a random order. Also in both phases of the experiment participants were allowed to do several trials at the beginning until they were confident about the marking procedure.

4. Data Analysis

4.1 Data used

Mj_i- Distance judgment of i^{th} judgment street as marked in paper averaged over 19 subjects

MJ_i- Objective distance of of i^{th} judgment street (as used in the visualization software)

Mr_i- Distance judgment of i^{th} reference street as marked on the paper averaged over 19 subjects

Mr_{is}- Distance judgment of i^{th} reference street in meters averaged over 19 subjects

MR_i- Objective distance of i^{th} reference street

4.2 Analysis for Hypothesis I

Subjective distance judgment of vegetated condition (Mj_i) was plotted against the Subjective distance Judgment of non-vegetated condition (Mr_i*MJ_i/ MR_i) (in terms of lengths marked on the paper). The least square regression line for the data was plotted. Research hypothesis was tested by statistically testing the coincidence of the least square regression line with line $Y = X$.

4.3 Analysis for Hypothesis II

The analysis of data of hypothesis II was done by relating subjective distance judgment to the corresponding objective distance judgment.

The relationship between a particular subjective distance judgment and the corresponding objective distance was investigated in terms of two commonly used functions. In addition to the linear function, Stevens[12] power function has also been used. [13,14,15]

1) Linear Function

$$Y = a + bX$$

2) Power Function

$$Y = aX^b$$

Where Y = Subjective Distance, X = Objective distance, and *a & b* are constants

The analysis was done using the plot Subjective Distance versus Objective distance. For the analysis of the factors Growth Stage and Spacing, Subjective distance ($Mj_i{*}Mr_{is}/Mr_i$) was plotted against Objective distance (MJ_i) (in terms of lengths in the real environment). For the analysis of Species factor, Subjective distance (Mj_i) was plotted against Objective distance ($MJ_i{*}Mr_i/Mr_{is}$) (in terms of lengths marked on the paper).

The least square regression lines were plotted for both linear and power functions. Using the regression analysis, the values of constants *a* and *b* were established. The goodness of fit was checked through coefficient of determination *(r^2)* and by testing the regression coefficient *(b)* for being significantly different from zero$\left(t = b/\sqrt{(s^2/\sum (u - \hat{u})^2)}\right)$ *s= standard error of the estimate, u= objective distance,* $\hat{u}$ *= Mean of objective distance)* for both functions (Table 1). In addition Runs Test [16] was done to examine whether such regression lines systematically deviate from the data. The efficiency of linear versus power function to describe the data was tested using Akaike`s Information Criteria (AIC) [17]. Hypothesis for each factor was checked by checking the coincidence of the above curves at different levels of each factor.

5. Results

5.1 Hypothesis I

The null hypothesis that the introduction of vegetation would not change the subjective distance judgment of the respondents was tested. Accordingly the data of the plot Subjective distance (vegetated) versus Subjective distance (non vegetated) should have yielded a $Y = X$ relationship. The linear regression model yielded $Y = 8.721 + 0.8511X$. The null hypothesis was rejected significantly *($p < 0.001$)*. Thus the results suggest that the introduction of vegetation has changed the subjective distance judgment significantly. In order to investigate whether such introduction would lead to overestimation or underestimation, the authors conducted a simple test by considering the number of data points below and above the $Y = X$ line. Out of 72 data points 61 points (84.72%) were above the line $Y = X$ and while 11 points (15.28%) were below the line $Y = X$. These results suggest that the introduction of vegetation has lead to an overestimation in the subjective distance judgment.

5.2 Hypothesis II

Hypothesis IIa – Effect of Growth Stage

The goodness of fit of regression lines: Both linear and power functions well described the data of all 3-growth stages (Table 1). Both r^2 value and statistical test on regression coefficients *b* revealed the existence of highly significant correlation for both functions for all growth stages. The Runs Test indicated that the deviation of data from the regression models were not significant. The AIC test indicated that the preference for the linear model to the power model for all three growth stages.

Effect of growth stage on distance cognition: The null hypothesis that data belonging to all three growth stages could be explained by one regression curve was tested against alternative hypothesis of usage of different curves to describe data. For both power and linear functions, the data did not reject the null hypothesis implying that three data sets did not support different curves. Thus results suggest that the different growth stages would not induce different cognitive distances at perspective level.

Hypothesis IIb– Effect of Spacing of trees

The goodness of fit of regression lines: Both linear and power functions well described the data of all 3 tree spacing (Table 1). Both r^2 value and statistical test on regression coefficients *b* revealed the existence of highly significant correlation for both functions for all three spacing. Runs Test indicated that the deviation of data from the regression models were not significant. The AIC test indicated that the preference for the linear model to the power model for all tree spacing levels.

Effect of spacing on distance cognition: The null hypothesis that data belonging to all three levels of tree spacing could be explained by one regression curve was tested against alternative hypothesis of usage of different curves to describe data. For both

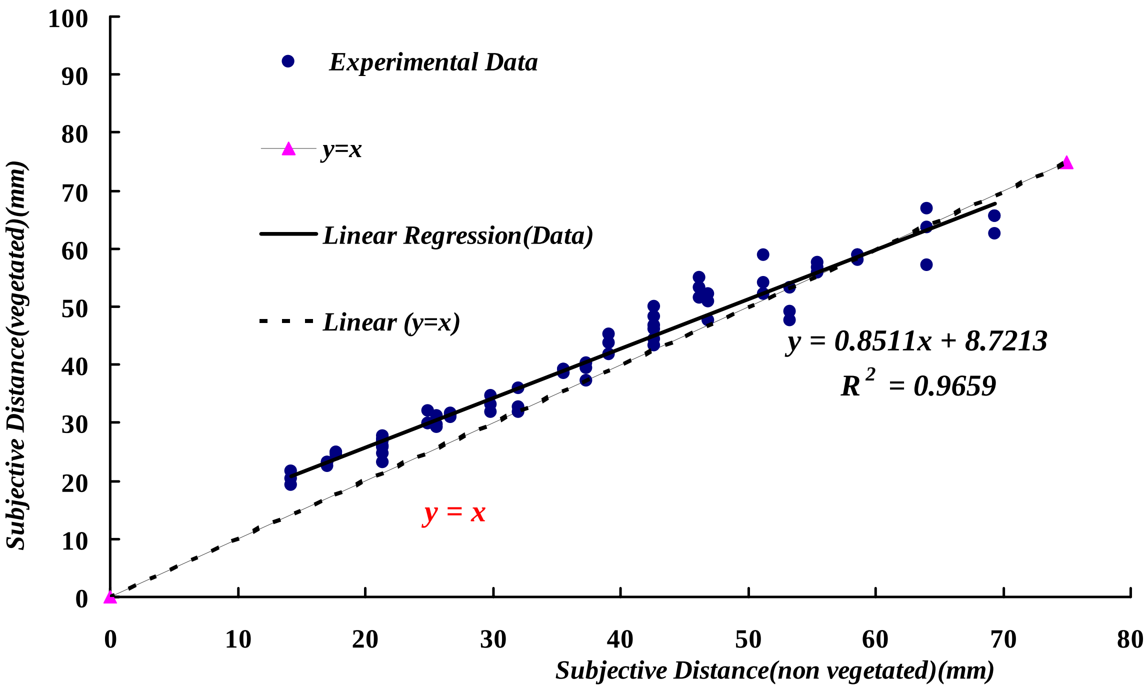

Figure 2 : Subjective Distance (vegetated) (Mj_i) Vs Subjective Distance (Mr_i*MJ_i/MR_i) (non vegetated)

power and linear functions, the data rejected the null hypothesis implying that three data sets supported different curves *($p<0.0001$)*. Thus results suggest that for a given objective distance different tree spacing would induce different cognitive distances. The magnitude to regression coefficient *b* increased with the increase in spacing. This implies that for a given objective distance the trees when spaced far apart would induces longer cognitive distance values than when spaced relatively closer.

Hypothesis IIc – Effect of tree species and canopy condition

*The goodness of fit of regression lines :*Both linear and power functions well described the data of all 4 types (Table 1). Both r^2 value and statistical test on regression coefficients *b* revealed the existence of highly significant correlation for both functions for all 4 types. The Runs Test indicated that the deviation of data from the regression models were not significant for tree species Ginko and Sakura for both linear and power functions. The two canopy forms of Zelkova species (summer canopy and winter canopy) showed significant deviation from the linear model while the deviations from the power model were not significant. The AIC test indicated that the preference for the power model to the linear model for all four species.

Effect of tree species on distance cognition: The null hypothesis that data belonging to four species types could be explained by one regression curve was tested against alternative hypothesis of usage of different curves to describe data. For both power and linear functions, the data did not reject the null hypothesis implying that four data sets did not support different curves. Thus suggested that the different tree species would not induce different cognitive distances at perspective level.

Hypothesis IId – Effect of canopy condition

The goodness of fit of regression lines: Both linear and power functions well described the data of both summer and winter canopy condition (Table 1). Both r^2 value and statistical test on regression coefficients *b* revealed the existence of highly significant correlation for both functions of the two-canopy condition.

The Runs Test indicated that the deviation of data from the regression models were not significant for power model but significant for linear model. The AIC test indicated that the preference for the power model to the linear model by both canopy condition.

Effect of canopy condition on distance cognition: The null hypothesis that data belonging to both canopy conditions could be explained by one regression curve was tested against alternative hypothesis of usage of different curves to describe data. For both power and linear functions data did not reject the null hypothesis implying that three data sets did not support different curves. Thus results suggest that different canopy conditions would not induce different cognitive distance at perspective level.

6. Discussion

6.1 Presence of Vegetation and Distance Judgment

The outcomes of the investigations could be summarized in to the following points.

- The introduction of vegetation has affected the subjective distance judgment. The distances in the vegetated setting were overestimated in comparison to the non-vegetated setting.
- Trees belonging to different growth stages or different species do not induce different subjective distance judgments. Trees in full canopy do not induce distance judgments that are different from bare canopy condition.
- The spacing of trees would affect the cognitive distance judgment. Those trees placed far apart from each other would induce longer distance judgments in relation to those placed closer.

According to the results of Hypothesis I, the introduction of vegetation has lead to an increase in cognitive distance judgment. Such an overestimation effect could be brought about either due to the increase in volume of greenery or due to the segmentation of route by trees. Had the former argument been true, the results of Hypothesis II too should have provided consistent evidence. Neither the growth stage variation where the overall green volume increases for fully-grown trees nor variation of canopy condition where the leaf quantity was varied yielded significant variations in subjective distance judgments. The evidence from the variation of spacing of trees is in contradiction to this argument. The latter argument based on Route segmentation hypothesis stipulates that routes segmented by features will be felt subjectively longer than unsegmented routes. Accordingly, if the trees were treated as features that segment the routes, the vegetated setting would correspond to longer cognitive distance representation in comparison to non-vegetated setting. The data relating to Hypothesis I showed evidence consistent with this argument.

Yet the results relating to the tree spacing contradicts the Feature Accumulation Hypothesis the other acceptable hypothesis relating features to distance judgment. Feature Accumulation Hypothesis indicates that increased number of pathway features would lead to increased distance estimates. Accordingly, the subjective distance judgments of far spaced (where the number of trees were lesser) setting would have corresponded to relatively lower subjective distances though the data suggested vise-versa. Montello [7,15] after observing some discrepancies of several researches in this relation doubted the validity of this assumption and suggested that increased number of features may actually lead to decrease in distance judgment. Though there is some evidence from travel time studies, this phenomenon needs further clarification through experimental work in relation to distance cognition. Alternatively such a discrepancy could have been caused as a result of the line of trees appearing not as a set to different distinct features but as one continuous element.

In comparing the outcomes of this investigation with that of Serpa and Andreas[8] the two studies have produced results that do not agree with each other. While they found the tree size (growth stage factor in this study) and texture (species factor in this study) to be affective on the distance judgment, the results reported here showed neither growth stage nor tree species to be affective on distance judgment. Although mode of stimuli, photographs was same, the studies differ in terms of level of focus to the trees, which could have caused contradiction. The subjects of their study evaluated the distance from them to the tree, which was the single prominent object in the stimuli. On the other hand the stimuli in this study was a scene of a typical residential street where a combination of elements were present with non-being prominent. Also the task in this study did not specifically target trees where the subjects had to evaluate the distance to a sign on the road. Also the authors interpreted their results in terms of the level of familiarity and size distance invariance hypothesis and not due to any tree characteristics.

6.2 Distance Cognition and Human Behavior

The navigational tasks such as map-guided way finding or retaking a familiar route could successfully be executed with *route knowledge* even without incorporating distance knowledge. On the other hand route selection including search for a shortcut may demand the utilization of *configurational knowledge*, which incorporates the distance knowledge. The distance knowledge in this respect forms a vital source of information especially for human navigation decisions. The early work in this area had focused on consumer behavior where the store choice was studied in the light of subjective distance judgment. But recent studies have considered the importance of cognitive distance for route choice, destination choice or travel mode choice [7].

The outcomes of this work suggested that vegetated settings induce subjective distances that are longer than the subjective distances in a non-vegetated setting. Also the subjective distances for the settings of this study were always longer than the corresponding objective distances.

Table 1 Summary of Regression Analysis, Runs Test, AIC Test and Test for One Unified Model

			Growth Stage				*Spacing*		*Species*			*Canopy Status*	
		G1	*G2*	*G3*	*S1*	*S2*	*S3*	*G*	*Z*	*W*	*S*	*Z(Summer)*	*W(Winter)*
Coefficient of	*Linear*	0.881	0.956	0.959	0.962	0.983	0.976	0.898	0.888	0.972	0.959	0.888	0.972
determination(r2)	*Power*	0.892	0.962	0.953	0.967	0.983	0.976	0.919	0.918	0.981	0.961	0.918	0.981
Standard error	*Linear*	9.409	5.678	5.497	4.750	3.562	4.385	3.339	4.258	1.955	2.245	4.258	1.955
of estimate	*Power*	9.505	5.888	5.592	12.077	3.726	4.809	3.146	4.071	1.756	2.073	4.071	1.756
Regression	*Linear*	11.179	10.133	8.883	8.349	10.821	11.025	12.853	10.306	10.246	9.211	10.306	10.246
Intercept(a)	*Power*	3.582	3.503	3.136	2.856	3.574	3.854	3.740	3.423	3.936	3.966	3.423	3.936
Regression	*Linear*	1.598	1.644	1.667	1.498	1.678	1.733	1.067	1.153	1.144	1.135	1.153	1.144
Coefficient(b)	*Power*	0.826	0.836	0.864	0.862	0.838	0.826	0.734	0.760	0.717	0.703	0.760	0.717
Standard Error of	*Linear*	0.125	0.076	0.073	0.063	0.047	0.058	0.077	0.102	0.049	0.058	0.102	0.049
Regression Coefficient	*Power*	0.127	0.078	0.074	0.161	0.050	0.064	0.072	0.098	0.031	0.037	0.098	0.031
t Value	*Linear*	12.755	21.738	22.765	23.680	35.360	29.678	13.901	11.250	23.522	19.698	11.250	23.522
	Power	6.594	11.058	11.806	13.632	17.667	14.147	9.560	7.415	14.733	12.203	7.415	14.733
p value	*Linear*	6.E-12	8.E-17	3.E-17	1.E-17	1.E-21	8.E-20	1.E-12	3.E-09	2.E-14	4.E-13	3.E-09	2.E-14
(signinficance level)	*Power*	1.E-06	1.E-10	3.E-11	2.E-12	7.E-15	8.E-13	2.E-09	1.E-06	4.E-11	8.E-10	1.E-06	4.E-11
Runs Test													
Number of runs	*Linear*	16	16	15	16	15	14	7	6	6	8	6	6
	Power	16	15	15	15	15	14	6	8	8	8	8	8
p value	*Linear*	0.952	0.952	0.850	0.936	0.860	0.784	0.109	0.048	0.048	0.251	0.048	0.048
	Power	0.952	0.889	0.850	0.889	0.860	0.784	0.060	0.238	0.251	0.251	0.238	0.251
Deviation from	*Linear*	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	S.	S.	N.S.	S.	S.
the straight line	*Power*	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
AIC Test													
Evidence Ratio		1.12	1.71	1.31	1.06	2.02	3.99	3.55	2.44	7	4.08	2.44	7
Difference in AIC		-0.234	-1.073	-0.541	-0.116	-1.140	-2.768	2.536	1.784	3.892	2.812	1.784	3.892
Preffered Model		Linear	Linear	Linear	Linear	Linear	Linear	Power	Power	Power	Power	Power	Power
Test for One Unified Model													
P value	*Linear*	0.977			p<0.0001			0.670				0.9695	
	Power	0.978			p<0.0001			0.701				0.9122	
Fvalue	*Linear*	).1338(4,66)			29.54(4,66)			0.6757(4,64)				0.0314(2,32)	
	Power	).1117(4,66)			27.83(4,66)			0.6358(4,64)				0.09216(2,32)	
Rejection of Ho		D.N.R Ho			Reject Ho			D.N.R Ho				D.N.R Ho	

N.S.-Not Significant *S-Significant* *D.N.R Ho- Do Not Reject Ho*

Based on effort hypothesis which highlights the human desire to decide up on options that requires least effort, it could be argued that those felt to be relatively far would be less attractive. Such choices would have negative impact on usage of the space leading to less usage or abundance. In the case of pedestrians, if they feel their destination to be far their route choice and choice of travel mode may be affected. If such a subjective understanding would make a pedestrian on foot to get on to an automobile or a jogger to cut short his target, associated health implications may not be positive. With the understanding that cognitive distance along with other aspect of subjective spatial representation would differ from the respective objective measures it is important to understand the applicability of subjective measures in the presence of objective measures. Further up on experience if the users realize the misunderstanding created by subjective judgment such situation may lead to frustration. Thus it is important for the designer to understand how such possible illusions could be brought about by the designed space. Such a realization would not necessarily mean that the design should strictly convey the objective measures. But where such illusions could lead to serious misunderstandings, measures should be taken to rectify those.

7. Conclusions

In investigating the effect of vegetation on distance cognition the authors found that the introduction of vegetation to have a significant effect on cognitive distance at perspective level. Although the introduction of vegetation may lead to misjudgments in distance, the solutions should not necessarily be the reduction of trees. The knowledge of when, where and how such occurs could be extended in treating such misunderstandings through improved information and design of space.

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