CHAPTER EIGHT
Data Integration, Analysis and Discussion

As discussed in Chapter 7, data have been collected through a range of different data sources. There are four principal data sets that have been created by this research: movement tracking, information accessed through a PDA, observation data of participant actions and data from questionnaires. The integrated data and derived variables together provide elements of a comprehensive picture that can be used to study the behaviour, interaction and spatial information transactions between individuals, mobile devices and environments. Formatting and integrating the original data collected from the experiments is described in §8.1. The pre-experiment questionnaire is analysed in §8.2, whilst the questions relating to sense of presence in VR and the commonality of wayfinding strategies in VR and the real world in the post-experiment questionnaire are examined in §8.3. In §8.4 position, distance and time variables are analysed in terms of wayfinding behaviour. PDA spatial information usage is analysed in §8.5 and a classification of individual patterns of PDA usage is presented in §8.6. In §8.7 a number of group and individual case studies are provided.

8.1 Data Formatting and Integration

Data from the experiment results were collected through four different data sources: positional data tracked through the VR system, PDA spatial information usage data captured through the Cookies written and installed in the PDA (§6.2.3), observation data of participant actions recorded through an Access database with an interface programmed and installed in a laptop (§6.2.3), self-assessed individual spatial ability measures obtained through the pre-experiment questionnaire (§6.1 and Appendix II) and feedback to the experiments in the post-experiment questionnaires (§6.3 and Appendix V). These original data can then be categorised as follows:

- positional data with time showing the movement track of each participant: $P_i(t, x, y)$ along with head height data z and head movement data pitch, yaw and roll, as discussed in §7.5;
- PDA information usage: Info-PDA$_i$ $\{t, P_{type}, P_{mode}, P_{access}\}$ which are respectively the type of information acquired from the PDA (e.g. map information, route information), the mode by which it was acquired (e.g. through voice, text or map layout) and the way in which it was accessed (either click for new information or look again at the same information);

- observational data: $O_i\{t, B_{PDA}, B_{tcomplete}, B_{move}, B_{confidence}\}$ which are respectively the usage of PDA (such as rotation of the device and looking at PDA), the completion of individual tasks, movement characteristics (e.g. looking for street name, hesitation or making decision), and the level of confidence expressed during the wayfinding tasks;
- response data from the pre-experiment questionnaire on participant self-assessed spatial ability $SA_i\{S_{sd}, S_{mu}, S_{gsa}, S_{sa}\}$ which respectively represent the self-assessed sense of direction, map use, general spatial ability and spatial awareness (the details of these four aspects are discussed in §6.1 and §6.5.1); $TK_i\{TK_{route}, TK_{landmark}, TK_{map}\}$ presents individual tendency for route-oriented, landmark-oriented and map-oriented thinking in wayfinding, visual-spatial ability and technology familiarity;
- feedback data from post-experiment questionnaires on the experience of VR with respect to 'sense of presence', and commonality between wayfinding approaches adopted in VR environments and those used in the real world;
- sketch maps of the settings and written descriptions of the routes taken;

where i = 1 to 27 for each participant; *t* is the time recorded in seconds.

8.1.1 Formatting of the Original Data Sets

The positional track data record the movement of each participant, $P_i(t_i, x_i, y_i)$ i = 1 to 27. The (x, y) coordinates recorded through the VR system were not in the GB National Grid coordinate system. Following the principle of geo-rectification commonly used for satellite imagery, coordinates recorded through the VR system were compared with the coordinates in the GB National Grid system for shift, rotation and scaling in order to transform the original track data to the National Grid. No scaling and rotation was needed to position data in both settings U1 and U2. Only shift was required:

- $X_i = x_i + 485{,}273$, $Y_i = y_i + 237{,}528$ for setting U1
- $X_i = x_i + 553{,}831$, $Y_i = y_i + 238{,}435$ for setting U2

The track data, therefore, can be overlaid with OS MasterMap™ data. Data on head height z and head movement (pitch, yaw, roll) are not used for analysis in this thesis, and are only used to confirm observation data such as whether an individual was looking at the PDA or looking at street names. Thus no formatting has been carried out on these data. Furthermore, according to the observation records of resting time for each participant, the position data recorded by the VR system during these rest times were removed. Finally, for the positional track data, 54 data tables were created using time as index field covering all 27 participants in both settings U1 (total 43,985 positional track points) and U2 (total 44,156 positional track points).

PDA information usage data were recorded through Cookies installed in a PDA. There are 1132 recorded Cookie text files for the 27 participants, 463 files for setting U1 and 670 for setting U2. Scripts were written to extract, from these text files, the data on PDA information accessed and the access time, and to join all the records for each participant into a data table with time as the index field. Thus PDA information usage data were in 54 data tables comprising 27 tables for U1 and 27 tables for U2.

Participant overt actions were recorded through observation during the experiments. These were stored in Access database tables with time as the index field. These data tables were exported into 54 observation data tables which are for 27 participants in both settings U1 and U2.

For the pre-experiment questionnaire (§6.1 and Appendix II), responses to questions 1 to 17 were coded into numeric 0, 2, 4, 6, 8 and 10 representing answers from 'strongly disagree' to 'strongly agree'. The responses to questions 18 to 22 relating to familiarity with technologies were coded as 0, 2, 4, 6, 8 representing answers from 'never' used to 'daily' or 'weekly' usage. A spreadsheet was created for all 27 participants with all coded responses for all 22 questions along with participant demographic background. The last two questions were coded as descriptions in text format. The responses to the visio-spatial ability test were scored as the number of correct answers.

Feedback from the post-experiment questionnaire (§6.3 and Appendix V) was also coded into a spreadsheet. The responses to the first 6 questions concerning the experience after wayfinding in VR environment were coded as 0, 2, 4, 6, 8 and 10 representing answers from 'strongly disagree' to 'strongly agree'. The next 2 questions, which are descriptions of the experience in VR, were coded in text format. In addition, the features remembered and the description of routes taken were coded as descriptions in text format. Sketch maps drawn by each participant were also coded with scanned image and explanatory text with participant ID attached.

In all the above data sets, participant ID numbers were used as references for each individual and all names were removed from the data sets.

8.1.2 Data Integration

The data sets discussed above can be integrated to provide a data source containing a range of elements which permit the study of behaviour and interactions between individuals, mobile devices and environments. There were three stages for integrating these data sets. Firstly, the PDA information usage data sets and observation data sets for each participant were combined and sorted sequentially through the time field *t* in both data sets to form a time series. This process was carried out for all 54 tables covering 27 participants in both settings U1 and U2. Thus 54 actions tables were created comprising both PDA information usage and observed overt actions in a time sequence. Secondly, these action data tables were joined with positional track tables using common time field *t* as the primary key in both data sets. Thus geographical coordinates were added to the PDA information usage data and the observation data. This integration was performed on the 54 action tables and 54 positional track data tables. Thirdly, these data were further linked with individual spatial ability elicited from pre-experiment questionnaire data, using participant ID as a primary key. Responses from the post-experiment questionnaires were also linked with these data in the same way. Figure 8.1 illustrates these stages of the data integration.

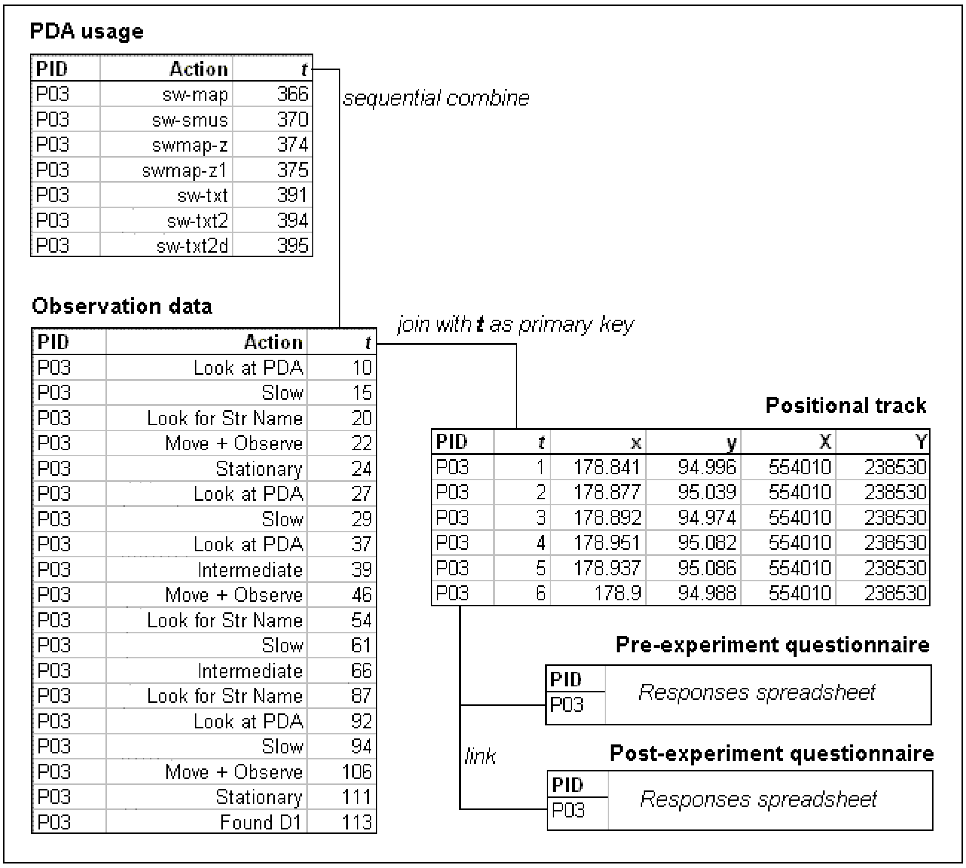


Figure 8.1 The data integration process

Through integrating the different data sets, additional variables could be calculated such as completion time, distance travelled, route taken, when and where information was required, when and where errors occurred. Additionally, individual and aggregated routes could be mapped and studied. Thus, the integrated data set was able to capture many pertinent aspects of information usage, overt actions, wayfinding performance, and an indication of user preferences. Table 8.1 provides an example of the finished integrated data table including some additionally calculated variables.

Ref	PID	Lapse	X	Y	Action	PDAuse	PDAelapse	Time4task	route	Distance	static-time	PDA-timeT	Plan-time
43646	P03	983	553923	238343					5	1.41	PDAuse	PDA-routeT	planning
43647	P03	984	553923	238343					5	0	PDAuse	PDA-routeT	planning
43648	P03	985	553923	238343					5	0	PDAuse	PDA-routeT	planning
43649	P03	986	553921	238344					5	2.24	PDAuse	PDA-routeT	planning
43650	P03	987	553921	238344					5	0	PDAuse	PDA-routeT	planning
43651	P03	988	553921	238344					5	0	PDAuse	PDA-routeT	planning
43652	P03	989	553921	238344					5	0	PDAuse	PDA-routeT	planning
43653	P03	990	553921	238344	Move + Observe			52	5	0	PDAuse	PDA-routeT	planning
43654	P03	991	553921	238344	Look at PDA	PDA-txt-look	23	53	5	0	PDAuse	PDA-routeT	planning
43655	P03	992	553921	238344					5	0	PDAuse	PDA-routeT	planning
43656	P03	993	553921	238344					5	0	PDAuse	PDA-routeT	planning
43657	P03	994	553921	238344	sw-map	PDA-mapS-click	3	56	5	0	PDAuse	PDA-mapS	planning
43658	P03	995	553921	238344					5	0	PDAuse	PDA-mapS	planning
43659	P03	996	553921	238344					5	0	PDAuse	PDA-mapS	planning
43660	P03	997	553921	238344					5	0	PDAuse	PDA-mapS	planning
43661	P03	998	553921	238344					5	0	PDAuse	PDA-mapS	planning
43662	P03	999	553921	238344					5	0	PDAuse	PDA-mapS	planning
43663	P03	1000	553921	238344	sw-sall	PDA-mapS-click-lmk	6	62	5	0	PDAuse	PDA-mapS	planning
43664	P03	1001	553921	238344					5	0	PDAuse	PDA-mapS	planning
43665	P03	1002	553921	238344					5	0	PDAuse	PDA-mapS	planning
43666	P03	1003	553921	238344	sw-rdelmsa	PDA-mapS-click-strn	3	65	5	0	PDAuse	PDA-mapS	planning

Figure 8.1 Example of integrated data table.

8.2 Analysis of Pre-Experiment Questionnaire

8.2.1 Variables

Four variables indicating individual spatial ability have been derived from the results of the pre-experiment questionnaire. The first variable, denoted as S_{sd} in this thesis, concerns the sense of direction aspect of spatial ability. The initial value of variable S_{sd} for each participant is their combined total score for questions Q1 to Q5 in Table 6.2. The second variable, S_{mu}, reflects map use ability with its initial value as the combined total score of questions Q9 and Q10 in Table 6.2. General spatial ability as the third variable, denoted as S_{gsa}, concerns people's ability performing spatial tasks related to wayfinding in life. The initial value of S_{gsa} is the combined total score of questions Q11 to Q14 in Table 6.2. The fourth variable, S_{sa}, reflects people's spatial awareness with its initial value as the combined total score of questions Q15 to Q17 in Table 6.2. All the above combined scores are with equal weighting. Therefore, individual spatial ability can be expressed as $SA_i\{S_{sd}(i), S_{mu}(i), S_{gsa}(i), S_{sa}(i)\}$ with i = 1 to 27 from the responses to the questionnaire. Because of the different number of questions included in each of these four aspects, the final value for each composite indicator was the initial value of combined total scores divided by the corresponding number of questions in each aspect, in order that the four variables can be represented on the same scale (0, 10). Table 8.2 shows these four variables for each participant.

	S_{sd}	S_{mu}	S_{gsa}	S_{sa}
P02	7.6	8	9.5	8.7
P03	8	9	6	8.7
P04	6.4	10	8	10
P05	3.6	6	2	4
P06	3.6	6	3	6.7
P07	8	6	7	7.3
P08	3.6	10	1	8
P09	8	10	8.5	8.7
P11	6.8	9	7.5	9.3
P12	8.4	10	8	10
P13	3.6	7	7.5	8
P14	8.4	10	8	9.3
P15	6.8	10	7	8
P16	6.4	7	7.5	8
P17	4.4	6	4	5.3
P18	3.6	7	4	5.3
P19	4	3	2.5	5.3
P20	6	10	6	7.3
P21	4	8	4.5	7.3
P22	6.4	7	4.5	4
P23	6.4	8	6	7.3
P24	5.6	10	4	8
P25	5.6	7	5.5	7.3
P26	8.8	9	6.5	8
P27	5.6	7	5	7.3
P29	6.4	10	5.5	10
P30	6	9	5.5	8

Table 8.2 Four composite variables indicating individual spatial ability.

The next set of variables $\{TK_{route}(i), TK_{landmark}(i), TK_{map}(i)\}$ where i = 1 to 27, indicate individual tendency for route, landmark and map thinking during wayfinding. These were derived from the responses to Q6, Q7 and Q8 in the pre-experiment questionnaire (Table 6.2). As shown in Figure 8.2 a higher proportion of the participants reported that they tend to have landmark-orientated thinking while carrying out wayfinding tasks in comparison with route-oriented or map-oriented thinking. In addition, participants showed that route-oriented, landmark-oriented and map-oriented thinking are not mutually exclusive to each other. These three variables $\{TK_{route}, TK_{landmark}, TK_{map}\}$ will be further analysed in the next Section.

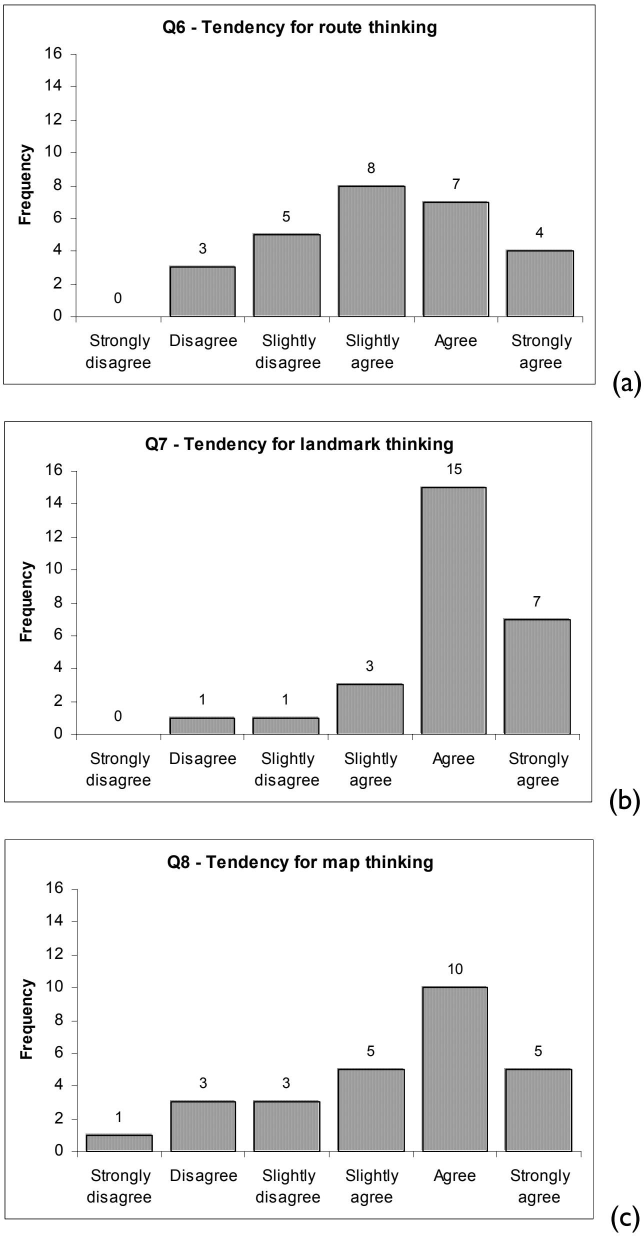


Figure 8.2 Bar charts of the responses to questions: (a) Q6; (b) Q7; (c) Q8.

The responses for the next part of the pre-experiment questionnaire give an indication of individual's usage of related technologies (Table 6.2). Through these questions (see Appendix II) it is possible to detect variations amongst the selected participants in terms of familiarity with technologies. The set of technologies are: use of mobile phone; use of text messaging; use of palm computer; playing electronic games; usage of the Internet for finding maps or travel instructions; and having experience of VR. The purpose is to see if individuals are generally familiar with or have experience of these technologies. From the responses, all participants were familiar with the Internet and have had experience of using the Internet to find maps and travel instructions. They all also had knowledge of using mobile phones, although some of them expressed that they did not like using mobile phones due to personal preferences. Half of the participants used palm computers at least rarely, but all had experience of using computers. The majority of participants did not play electronic games (only three out of the twenty-seven participants played electronic games regularly). The participants had different levels of experiences of VR environments, such as on screen, projected wide screen and immersive VR. To conclude, although there are different levels of usage of these various technologies, all participants are technology-aware and familiar with using the Internet and computers. Therefore, the variables on differences in familiarity with technologies have not been considered further in this research.

The variable, VT(i) where i = 1 to 27, is the total score of the responses to the visio-spatial ability test in the pre-experiment questionnaire (see §6.1 and Appendix II). The results, summarised in Figure 8.3, show a range of scores with only one third of participants giving a correct answer to all five questions. These results will be further used in §8.2.3 in relation to other spatial variables.

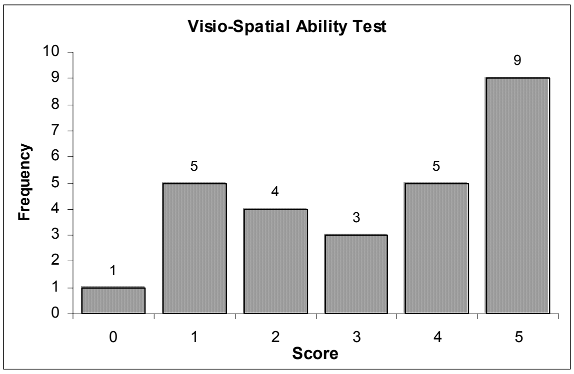


Figure 8.3 Results of visio-spatial ability test

8.2.2 Classifications

All 27 participants were grouped according to their self-assessed spatial ability which is represented through the four composite variables {S_{sd}(i), S_{mu}(i), S_{gsa}(i), S_{sa}(i)} (where i = 1 to 27) discussed in the previous Section. Ward's method (Ward, 1963) with Euclidean distance was used to classify the participants. Ward's method is an analysis of variance approach and is generally regarded as effective though with some tendency to create small sized clusters. The data used are shown in Table 8.2 above. From the results shown in Figure 8.4, there is considerable linkage distance between three broad groups marked 1, 2 and 3. Because these three groups are established based upon the spatial ability variables SA{S_{sd}, S_{mu}, S_{gsa}, S_{sa}}, they are denoted as SA-G1, SA-G2 and SA-G3 in this thesis. A Kruskal-Wallis test was carried out for these three groups for each of the spatial ability variables. The Kruskall-Wallis test is a non-parametric equivalent of one-way ANOVA used to compare three or more groups based on ranks (Griffith and Amrhein, 1991). From the results shown in Table 8.3, the three groups are significantly different (p < .005) for all four variables {S_{sd}, S_{mu}, S_{gsa}, S_{sa}} with respect to spatial ability. The three group classification is therefore taken as being sound.

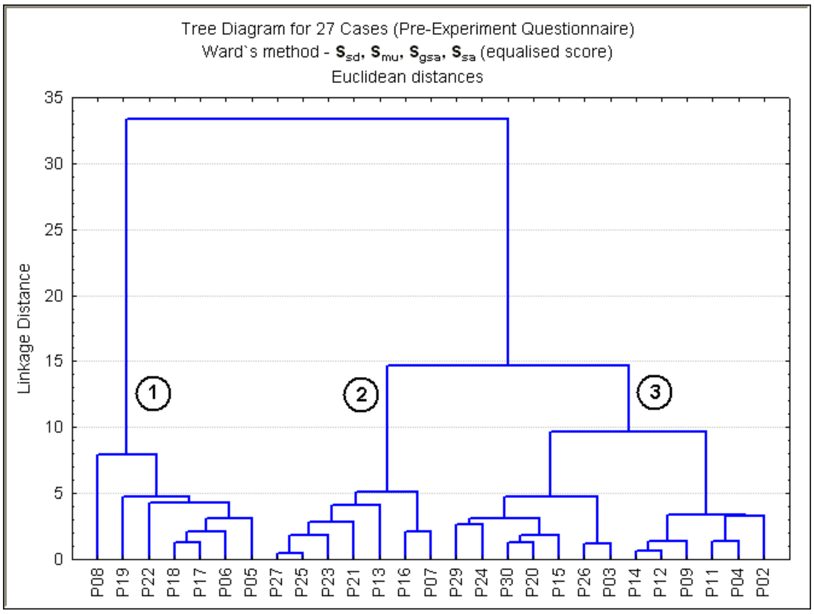
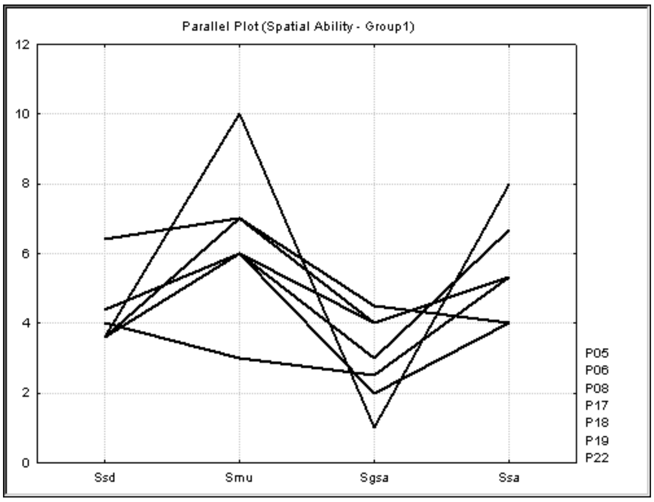


Figure 8.4 Classification based on participant spatial ability

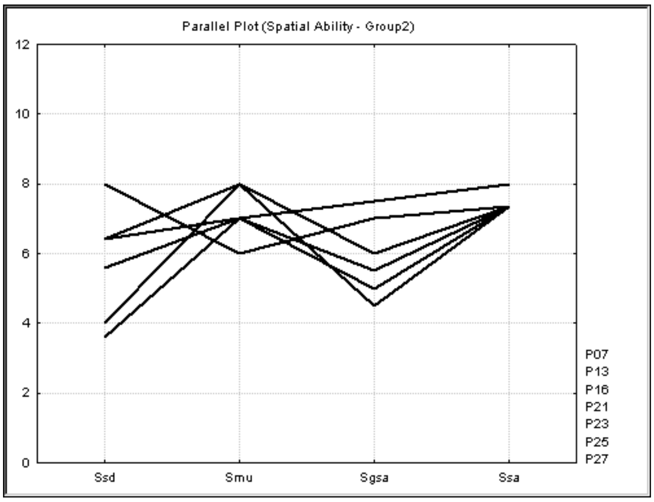
Variable	Kruskal-Wallis test for three SA groups
S_{sd}	H (2, N= 27) =13.42423 p =.0012
S_{mu}	H (2, N= 27) =16.51543 p =.0003
S_{gsa}	H (2, N= 27) =14.89946 p =.0006
S_{sa}	H (2, N= 27) =17.49137 p =.0002

Table 8.3 Kruskal-Wallis test for three SA groups

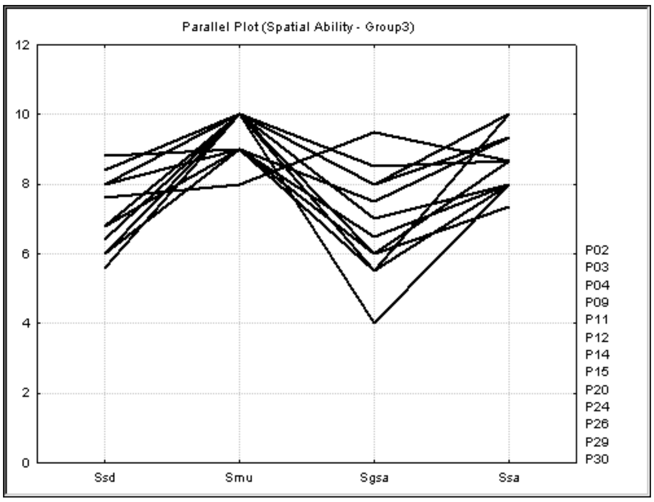
The scores of all participants in the three different groups (SA-G1, SA-G2 and SA-G3) are plotted against the four spatial ability variables S_{sd}, S_{mu}, S_{gsa} and S_{sa} in parallel plots (Figure 8.5). The participants in Group SA-G1, shown in the parallel plot of Figure 8.5(a), generally have lower scores on all four variables compared with the other two groups, particularly on sense of direction S_{sd} and general spatial ability S_{gsa}. Compared with Group SA-G1 and Group SA-G2, the participants in Group SA-G3 have higher scores on all four variables as shown in Figure 8.5 (c). For the participants in Group SA-G2, the scores are generally intermediate between Group SA-G1 and Group SA-G2 (Figure 8.5(b)). These parallel plots also demonstrate that participants in all three groups assessed themselves with higher scores on map usage S_{mu}, and spatial awareness S_{sa} than the other two variables, that is sense of direction S_{sd} and general spatial ability S_{gsa}.



(a)



(b)



(c)

Figure 8.5 Parallel plots: individual scores for four variables S_{sd}, S_{mu}, S_{gsa}, S_{sa}: (a) SA-G1; (b) SA-G2; (c) SA-G3

The classification using Ward's method was also carried out for 27 cases based on the variables {TK_{route}, $TK_{landmark}$, TK_{map}}, which indicate individual tendencies for route-oriented, landmark- oriented or map- oriented thinking. Three broad groups marked A, B and C in Figure 8.6 can be identified, and are denoted as TK-G1, TK-G2 and TK-G3 in this thesis. The Kruskal-Wallis test was also carried out for these three groups. The results, given in Table 8.4, show significant differences between the three groups (p < .05) for all three variables {TK_{route}, $TK_{landmark}$, TK_{map}}.

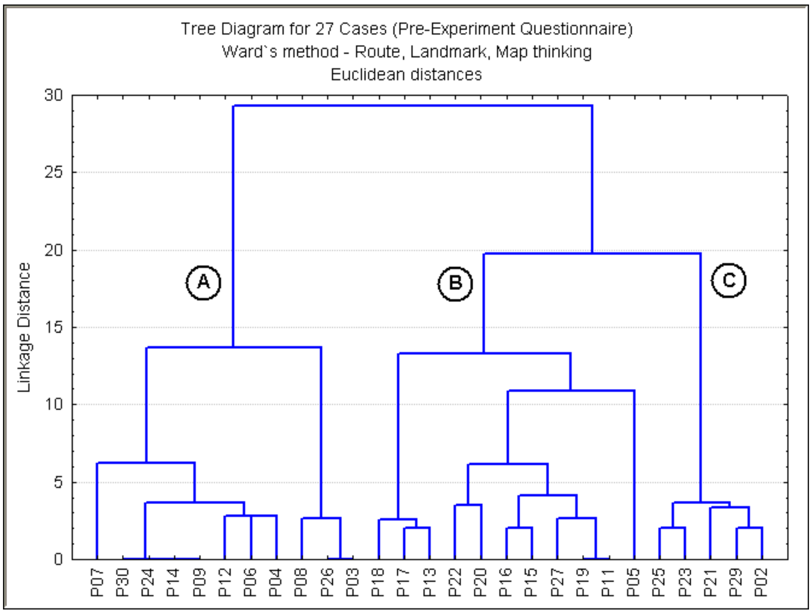


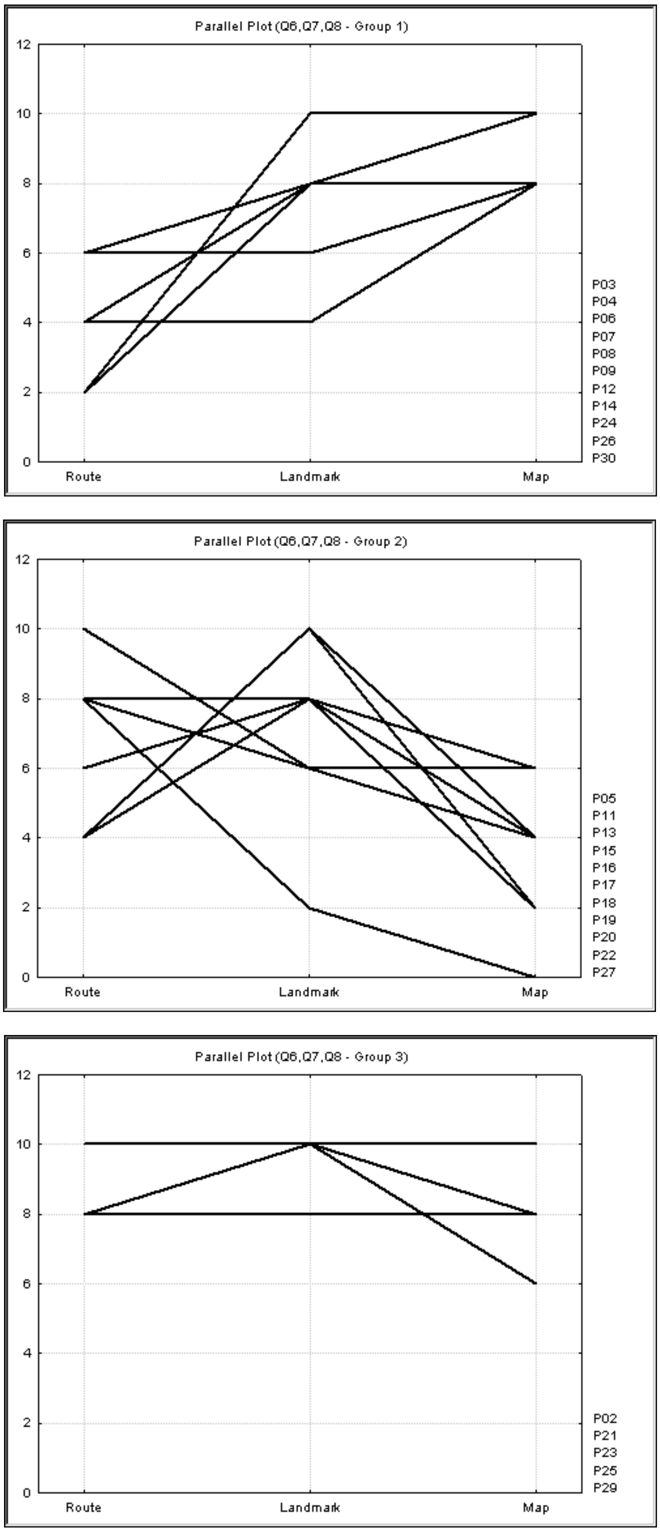
Figure 8.6 Classification of participant tendency for route, landmark and map thinking

Variable	**Kruskal-Wallis test for three TK groups**
Route	H (2, N= 27) =13.24033 p =.0013
Landmark	H (2, N= 27) =7.310186 p =.0259
Map	H (2, N= 27) =19.69620 p =.0001

Table 8.4 Kruskal-Wallis test for three TK groups

Parallel plots were also used to show the scores of the three variables TK_{route}, $TK_{landmark}$, TK_{map} for all participants in these three different groups (TK-G1, TK-G2 and TK-G3). The parallel plots for each group are given in Figure 8.7. Shown in Figure 8.7(a), Group TK-G1 exhibits a lower self-assessed tendency for route-orientated thinking with higher self-assessed tendency for map-orientated thinking alongside landmark-orientated thinking. Figure 8.7(b) indicates that Group TK-G2 has a self-assessed tendency for route-oriented thinking alongside landmark-orientated thinking with least self-assessed tendency for map-orientated thinking.

Group TK-G3 (Figure 8.7(c)) expressed a high self-assessed tendency for all modes of thinking. Moreover, as demonstrated in these parallel plots, the modes of thinking are not mutually exclusive amongst the participants with landmark-orientated thinking common to all three groups.



(a)

(b)

(c)

Figure 8.7 Parallel plots: individual scores for TK_{route}, $TK_{landmark}$, TK_{map}:
(a) TK-G1; (b) TK-G2; (c) TK-G3

Furthermore, the SA and TK groups were tested for differences in respect to variable VT – derived from the responses to the visio-spatial psychometric test. In both cases no significant differences were found. This would appear to be consistent with the opinion of some researchers (see §3.2.2) that psychometric testing has weak association with spatial ability in real-world wayfinding.

Discussion: As discussed in §3.2.2 and §3.4, individual spatial ability can be viewed from different perspectives and measured in different ways. Individual spatial ability has previously been studied in relation to various measures of wayfinding ability. In such studies, individuals have usually been grouped into having 'good' or 'poor' sense of direction according to their self-assessed spatial abilities (e.g. Cornell *et al.*, 2003). From the results presented here, three, rather than two, groups are identified based on composite variables S_{sd}, S_{mu}, S_{gsa} and S_{sa} with regard to individual sense of direction, map use, general spatial ability related to wayfinding and spatial awareness. The tests show that there are significant differences between each of these three groups. Two of these groups can be identified as self-perceiving 'good' (high SA-G3 scores) and 'poor' (low SA-G1 scores) spatial abilities. However, the existence of a third Group SA-G2 with intermediate but distinctive spatial ability scores suggests that self perception of individual spatial ability may not be as clear cut as the binary divide of 'good' versus 'poor' ability has previously suggested. This in turn suggests that the emphasis on studying individual spatial ability should be more on how such ability reflects on wayfinding behaviour. Moreover, the differences in individual spatial ability may also reflect differences in preference for different types of spatial information required while carrying out spatial tasks such as wayfinding.

Three different groups TK-G1, TK-G2 and TK-G3 were also identified regarding individual perceived tendencies towards route-oriented, landmark-oriented and map-oriented thinking for wayfinding activities. There is significant difference between these three groups according to the statistical test results (Table 8.4). These three tendencies correspond to the types of spatial knowledge discussed in §3.3.1. From the results shown in Figure 8.6 and Figure 8.7, the participants in Group TK-G1 perceive clear tendency towards map-oriented thinking, whilst the participants in Group TK-G2 perceive clear tendency towards route-oriented thinking. However, the results also indicate that the three groups are not identified with a single, mutually exclusive tendency for route-oriented, landmark-oriented or map-oriented thinking. In particular, landmark-oriented thinking is not a factor which could be used to differentiate between these groups. Participants in all three groups reported that they tend to have landmark-oriented thinking. Thus, landmarks could be considered as an important element in both route-oriented and map-oriented thinking.

Regarding the three variables TK_{route}, $TK_{landmark}$, TK_{map}, the Kruskal-Wallis test indicates that there is no significant difference between three spatial ability groups SA-G1, SA-G2 and SA-G3. A cross classification table (Table 8.5) is used here to show the number of participants in each of three SA groups (SA-G1, SA-G2 and SA-G3) and in three TK groups (TK-G1, TK-G2 and TK-G3). Interestingly, the numbers in Table 8.5 display that the majority of the participants in Group SA-G3 (with high score in spatial ability) tend towards map-oriented thinking, whilst a larger proportion of the participants in Group SA-G1 (with low score in spatial ability) tend towards route-oriented thinking. The participants in Group SA-G2 (with intermediate score in spatial ability) tend to have mixed modes of thinking. In other words, there is no clear majority of participants in Group SA-G2 who tend to prefer one of route-oriented, landmark-oriented or map-oriented thinking.

	TK-Group		
SA-Group	TK-G1 (map + landmk)	TK-G2 (route + landmk)	TK-G3 (all)
SA-G1 (low score)	2	5	
SA-G2 (intermediate score)	1	3	3
SA-G3 (high score)	8	3	2

Table 8.5 A cross classification of SA groups and TK groups

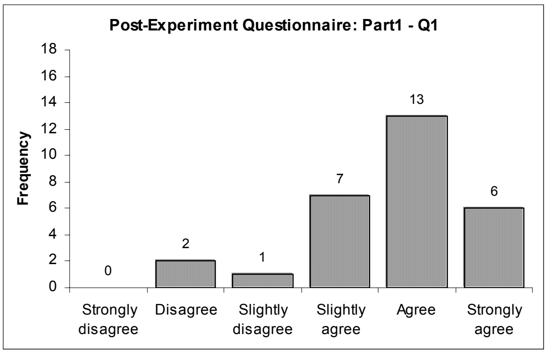
These spatial ability groups and their self-perceived tendencies towards route/landmark/map thinking groups will be analysed together with their observed spatial information usage and observed wayfinding behaviours in later sections.

8.3 Analysis of Post-Experiment Questionnaire

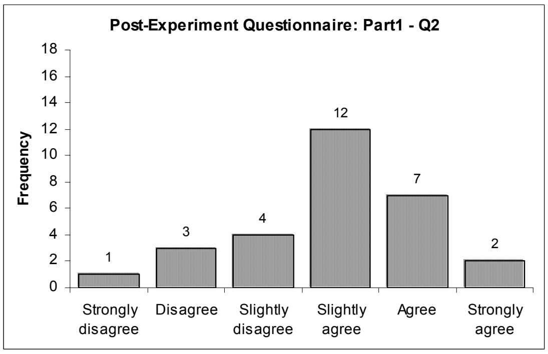
Part of the post-experiment questionnaire has important bearing on the validity of the experiment in VR environment. Thus this Section examines participant feedback on sense of presence in the VR test environment and the commonality of wayfinding strategies used in VR test environment and in the real-world prior to analysis of wayfinding data. In part 1 of the post-experiment questionnaire, questions Q1 to Q6 elicited the feedback information stated on the captions to Figures 8.8 (a) to (f). The focus of the responses shown in Figure 8.8 (a) to (d) is on the sense of presence after the wayfinding experiences in the VR test environment. There were 29[1] participants who answered this part of the questionnaire. From all four questions, the balance is clearly that most respondents experienced a sense of presence, which is consistent with the studies discussed in §4.2. Figure 8.8(e) shows that a smaller majority (19 of 27) of participants agree that they remember their experience of the

[1] 27 participants complete all parts of total experiments. Two participants only complete most of one set of wayfinding and Part 1 of feedback questionnaire (§7.4). Hence 29 participant responses are analysis in this Section.

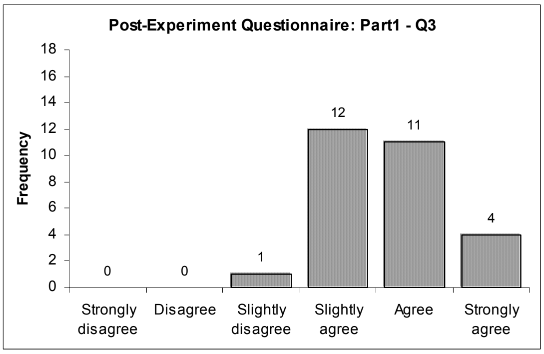
virtual town in the same way as they would remember places they had visited. The responses to the further two questions which emphasise the feedback on their wayfinding behaviour in VR environments reveals the overwhelming view that participants felt that they used a similar approach and similar features in the VR environment for wayfinding as in the real world.



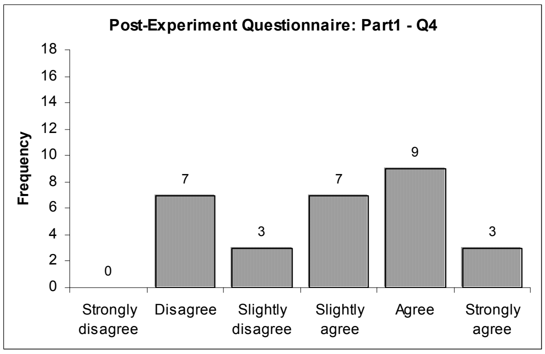
(a) have a sense of ‘being there’ in the street



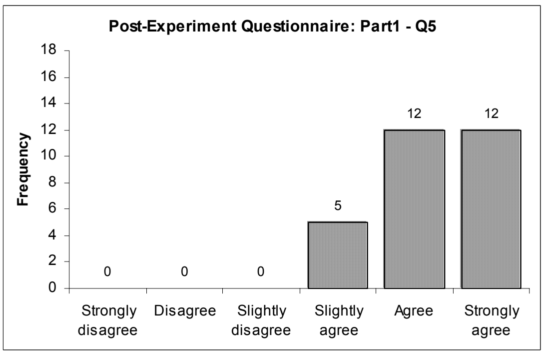
(b) the virtual town becomes the ‘reality’, almost forget about the ‘real world’ of the laboratory



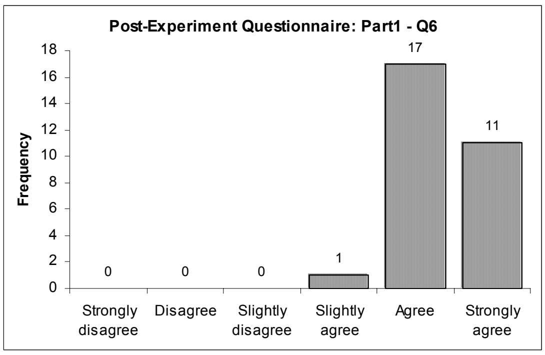
(c) feel like just visited somewhere instead of just looking at some images



(e) remember the virtual town experienced in the same way as remembering some visited places



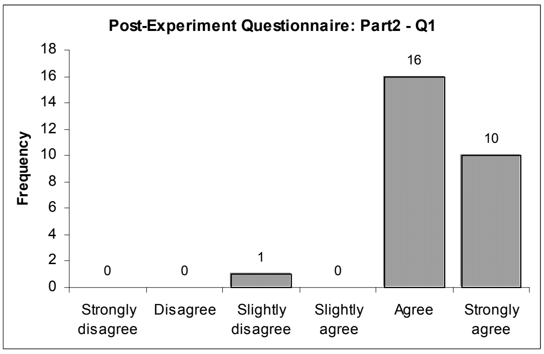
(e) find my way in these VR environments in a similar approach as I do in the real world



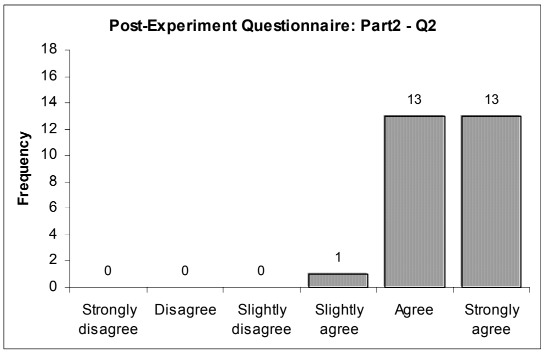
(f) use similar features to find my way around in these VR environments as I do in the real world

Figure 8.8 Bar charts of responses of the post experiment questionnaire Part 1 (Q1 to Q6)

In part 2 of the questionnaire, which was completed by participants after their wayfinding tasks in the second setting, two of the questions shown in Figure 8.8(e) and (f) in the part 1 were repeated so that consistency of the responses could be seen. There are 27 participants who answered these two questions in part 2 because two of 29 participants only completed the wayfinding tasks in one of the settings. Shown in Figure 8.9 (b), all 27 participants agreed that they use similar features in the VR environment for wayfinding as in the real world, whilst 26 out of 27 participants agreed that they use a similar approach in the VR environment for wayfinding as in the real world. Moreover, the responses from the debrief interview further confirmed the commonality in the strategies and features used in wayfinding during the experiment and that used in the real world.



(a) find my way in these VR environments in a similar approach as I do in the real world



(b) use similar features to find my way around in these VR environments as I do in the real world

Figure 8.9 Bar charts of responses of the post experiment questionnaire Part 2 (Q1 and Q2)

Discussion: The responses elicited from the above questions show the general agreement among the participants that there is a degree of sense of presence whilst they were in the VR urban environments. As discussed in Chapter 4, because of the ethereal nature of 'presence' and the ways in which participants might interpret and measure the degree of 'being' there, it was anticipated that the responses to these questions would show various levels of certainty. The results shown here are consistent with the general findings in the studies discussed in §4.2 and §4.3. More importantly, the responses to the two questions which concern the commonality of wayfinding strategies used in the VR test environment and in the real-world shows that all participants reported that they use a similar approach and features in the VR urban environments during the wayfinding experiments as they do in the real world. This finding is consistent between the two sets of wayfinding experiments. This has important bearing on the validity of the methodology adopted in these experiments.

8.4 Position, Distance and Time

In this Section the focus is on the $P_i(t, X, Y)$ i = 1 to 27 collected every second on participants' movements while undertaking the wayfinding tasks in the two urban settings. The track position can be studied as intensity maps whilst the two key variables extracted from the tracks – distance travelled and time taken for completion – can also be analysed. The positional track data, as discussed in §8.1.1, were transformed into the GB National Grid coordinate system. Thus, all position points could be referenced with the corresponding features in the OS MasterMap™ product. Furthermore, from the positional data, the distance travelled for each wayfinding task can be calculated for all participants. Also, for each participant, the completion time can be calculated for each wayfinding task. There are six separate wayfinding tasks to different destinations as from a starting point to D1, D1 to D2, D2 to D3, D3 to D4, D4 to D5 and returning to the starting point (see §6.4). These 6 tasks will be referred to as Route1 to Route6 in this thesis.

8.4.1 Spatial Distribution of Tracks

From the complete positional track data for each of the 27 participants, a general picture can be mapped of the routes that are most frequently travelled and the locations where participants tend to pause or stop. For urban setting U1, the 27 positional data tables were combined to form a new positional data table comprising all participant track data. This combined file contained a total 43,985 points. An intensity map (Figure 8.10) of these track points was created in ArcGIS, using kernel density estimation with a 1 metre grid cell and a 10 metre bandwidth. The intensity map was overlain onto the base map of the area, marked with starting/finishing points of the prescribed wayfinding tasks and the five destinations for each of the tasks (D1 to D5). As shown in Figure 8.10, the locations with highest densities are the start point of the whole wayfinding experiment and the destinations of each separate task (which are also the start points for the next task in the sequence) where the participants usually access information from the PDA as part of their planning/determining which routes are to be taken next. Another set of locations with high intensity are road junctions; however, some of the road junctions have higher intensities than others. Some road junctions present only a simple choice of routes that might be taken, whilst others pose greater challenges, as manifest by the higher intensities at roundabout junctions compared with other junctions in this setting. In addition, the diversity of routes taken by participants to reach the same destinations can also be clearly seen, although some routes are shown as having been taken more frequently as options than others. The intensity map also illustrates that some starting points for individual tasks have higher densities than others. For instance, the density for the starting points at D1 and D2 are higher than at D4. Hence less time is spent on average at D4 than at D1 and D2 before taking the route for the next task.

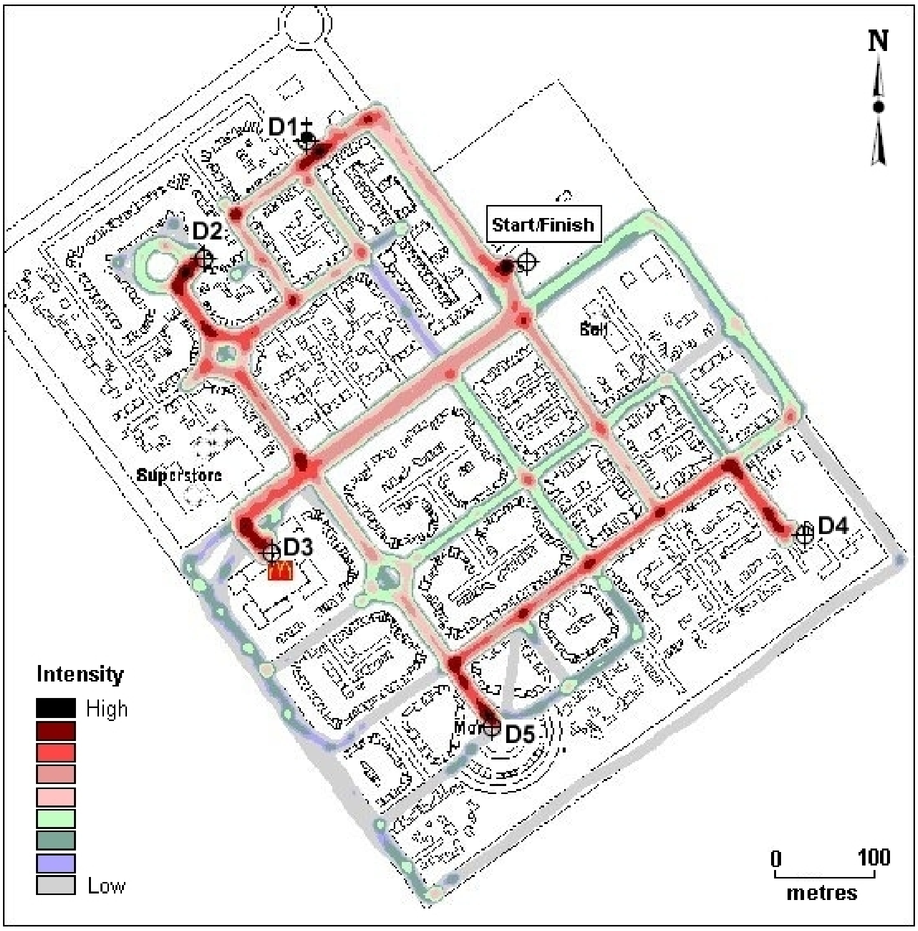


Figure 8.10 Intensity map of track points for all participants – setting U1

The same procedure was carried out to create an intensity map for all positional track points (all 27 participant tracks) in urban setting U2. There are a total of 44,156 track points. This intensity map was also overlain onto the base map for the area, with starting/finishing points and the five destinations for each task (D1 to D5) marked (Figure 8.11). Destinations D1 to D5 also served as the starting point for the subsequent wayfinding task. From this density map, a similar pattern can be identified as in setting U1 (Figure 8.10), that is, the highest densities are mostly located at starting points. At some of the destination points such as D2 and D3, there are several high intensity points rather than a single high density point. This is because these locations are more open (wider space), as in the case of squares which have a number of arrival points and many choices for leaving on the next task. Another set of locations with high intensities are road junctions. These appear different from the density distributions at road junctions in setting U1, as most of the road junctions in setting U2 consistently have higher intensities. This suggests that most of the junctions in U2 pose greater wayfinding challenges than those in U1. Diversity of routes taken can also be observed. Another particular location in this setting is a cul-de-sac with very high densities. Here the spatial layout posed certain difficulties for certain participants in their wayfinding tasks. This will be studied further in §8.7 together with spatial information use.

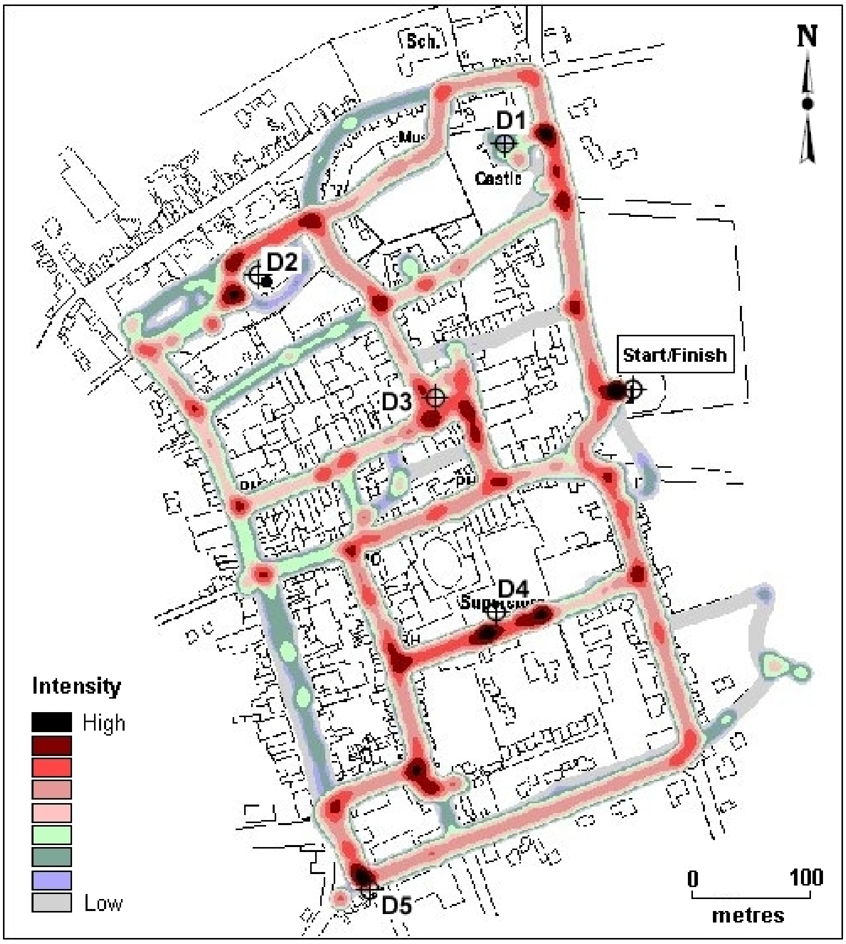


Figure 8.11 Intensity map of track points for all participants – setting U2

From the data recorded, all 27 participants reached the prescribed destinations in both settings. Hence, all participants were able to find their way using the information accessed through the PDA, although some experienced greater difficulty than others. As shown in Figure 8.10 and Figure 8.11, different routes were chosen by participants. The completion times also varied amongst the participants for each of the wayfinding tasks. The following sections will discuss the distance travelled variable and the completion time variable derived from the positional data. In the Sections that follow, a 'route' denotes the path taken between successive destinations and the routes are numbered thus: Route1 for the path taken to destination D1.

8.4.2 Distance Travelled

Distances travelled during the wayfinding tasks, denoted as $D_{travelled}$, were calculated for each setting from the positional track data $P_i(t_i, X_i, Y_i)$, i = 1 to 27 (for each of the 27 participants). Six variables were derived: $D_{travelled\text{-}total}$, $D_{travelled\text{-}R1}$, $D_{travelled\text{-}R2}$, $D_{travelled\text{-}R3}$, $D_{travelled\text{-}R4}$, $D_{travelled\text{-}R5}$ and $D_{travelled\text{-}R6}$, representing the distance travelled for the total wayfinding journey and the distance travelled for each successive route taken to reach D1 to D5 with Route6 the return to the starting point. These $D_{travelled}$ variables are in metres. The statistical summary of the $D_{travelled}$ variables for settings U1 and U2 are shown in Table 8.6 (a) and (b) respectively. The second column, 'Total', refers to the total wayfinding journey. For total distance travelled, $D_{travelled\text{-}total}$, the mean approximates the median for both settings U1 and U2. The distributions have a slight positive skew. As shown in Table 8.6 and corresponding boxplots in Figure 8.12, the distribution of variable $D_{travelled\text{-}total}$ for U2 is more skewed with higher kurtosis than the distribution of variable $D_{travelled\text{-}total}$ for U1. There is an outlier/extreme value in each of the boxplots, P02 in U1 and P17 in U2 respectively.

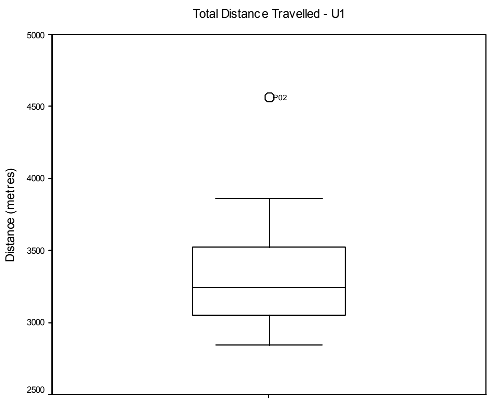
Urban Setting U1	**Total**	**Route1**	**Route2**	**Route3**	**Route4**	**Route5**	**Route6**
Mean	3313.44	317.13	452.08	449.61	898.30	516.13	680.20
Std. Error of Mean	74.99	10.23	24.35	29.73	33.38	11.45	24.42
Median	3242	297	425	398	837	509	640
Std. Deviation	389.65	53.15	126.53	154.50	173.45	59.52	126.90
Skewness	1.38	2.07	2.32	3.66	2.44	1.48	1.89
Kurtosis	2.64	3.97	9.55	15.78	6.04	4.10	2.19

(a)

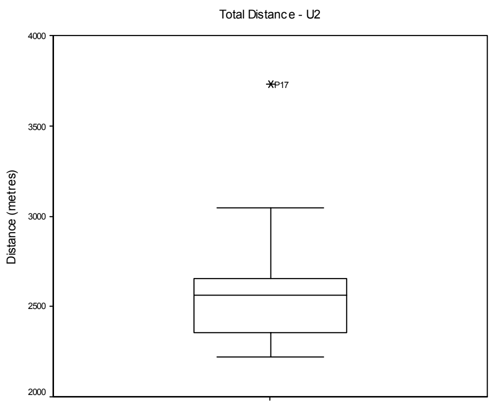
Urban Setting U2	**Total**	**Route1**	**Route2**	**Route3**	**Route4**	**Route5**	**Route6**
Mean	2570.27	236.94	420.16	402.83	454.13	402.97	653.26
Std. Error of Mean	60.37	6.08	13.90	25.82	18.33	13.82	34.00
Median	2563	229	400	397	420	370	604
Std. Deviation	313.71	31.61	72.25	134.15	95.23	71.83	176.68
Skewness	2.11	2.01	1.68	0.75	0.71	0.79	4.63
Kurtosis	6.30	4.94	3.18	-0.30	-0.48	-0.36	22.57

(b)

Table 8.6 Statistical summary of $D_{travelled}$ variables: (a) setting U1; (b) setting U2.



(a)



(b)

Figure 8.12 Boxplots for $D_{travelled\text{-}total}$ (n=27): (a) setting U1 and (b) setting U2.

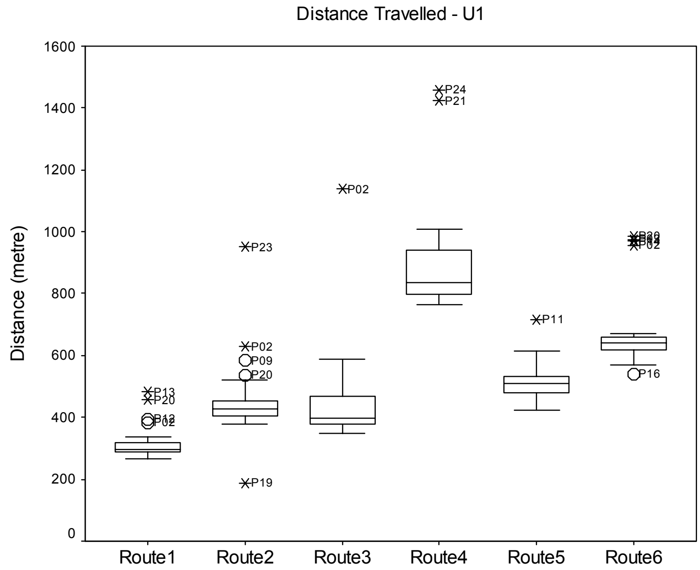
In order to test the normality of the distribution $D_{travelled\text{-}total}$, the Shapiro-Wilk test was chosen because the size of sample in these two data sets are both < 50. From the results shown in Table 8.7, the null hypothesis (H_0) can be rejected for $D_{travelled\text{-}total}$ in both U1 and U2. However, when the respective outlier/extreme values (P02 for U1, P17 for U2) are removed then H_0 can be accepted and the data taken as normally distributed. Thus the non-normality of the distributions is derived from a single outlier/extreme value in each case. It is worth noting that the participants that are outlier/extreme value are different in each case (P02 in setting U1, P17 in setting U2) and that it is not one participant who travelled further and took more time such as might occur with someone seriously getting lost in both settings. Nevertheless it would be prudent to use non-parametric test for statistical inference.

Urban Setting U1	Statistic	df	Sig.	***Urban Setting U2***	Statistic	df	Sig.
$D_{travelled\text{-}total}$	0.892	27	0.01**	$D_{travelled\text{-}total}$	0.816	27	0.01**
$D_{travelled\text{-}total}$ less P02	0.934	26	0.112	$D_{travelled\text{-}total}$ less P17	0.937	26	0.152

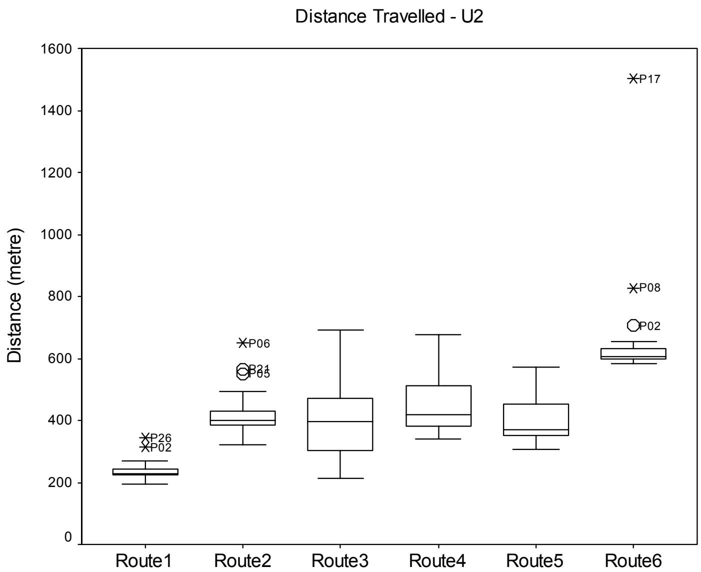
** This is an upper bound of the true significance.

Table 8.7 Normality test for variable $D_{travelled\text{-}total}$ (n=27)

Statistical summaries for the distance variable for individual routes are also given in Figure 8.6 (a) and (b). There is a considerable variability in the distributions in each of the routes in both settings. The variable distributions for some of the routes are more skewed and with higher kurtosis than others. This is also illustrated in the boxplots in Figure 8.13 (a) and (b). The median values are a good reflection of the relative length of route choices between successive destinations. The range of values in each boxplot arises from the individual route choices, some being longer than others. There are considerable numbers of outlier/extreme values. P02 in setting U1 generates outliers and extreme values in four out of the six routes, reflecting that this participant often became confused and repeated sections of route. P17 in U2 as an extreme value in $D_{travelled\text{-}total}$ discussed above (Figure 8.12 (b)), however, is an extreme value only in Route6. In this setting, P02 also appears as an outlier/extreme value in two of the routes for the same reasons as in U1. From the boxplots, it can be observed that, other than in the case of P02, it is not the same individuals that always generate outlying and extreme values. Thus, the differences in the distribution of each $D_{travelled}$ variable appear to vary according to the perceived complexity (by the participants) of route choice between successive destinations.



(a)



(b)

Figure 8.13 Distance travelled for six separated wayfinding tasks:
(a) setting U1 (n=27); (b) setting U2 (n=27)

As discussed in §6.4 and Table 7.1, half of the participants started the first set of wayfinding tasks in setting U1, whilst the other half started in setting U2, in order to control in the experimental design for the effects of sequencing. The variable $D_{travelled\text{-}total}$ between these two groups of participants is now tested to see if there is any sequence effect. 14 participants took U1 as their first setting for the wayfinding experiment, and another 13 participants took U1 as their second setting. A Mann-Whitney U test was used: $U(14, 13) = 87.00$, $p = 0.867$. The H_0 hypothesis could not be rejected. Therefore, this result shows that there is no significant difference in this variable between the participants starting U1 as their first setting and the participants taking U1 as their second setting. The same test was carried out for setting U2 with following result: $U(13, 14) = 75.00$, $p = 0.458$. Again, the H_0 hypothesis cannot be rejected. Thus, for both settings, the sequence in which the settings were used had no significant influence on the distance travelled or the routes chosen by the participants.

8.4.3 Completion Time

From the positional track data $P_i(t_i, X_i, Y_i)$ i = 1 to 27, the time taken to complete wayfinding tasks for each route and the total journey in each setting was calculated based on t_i and the (X, Y) locations of starting and finishing points of each task. This variable, denoted as $T_{completion}$ in this thesis, is the completion time. There is a set of $T_{completion}$ variables: $T_{completion-total}$, $T_{completion-R1}$, $T_{completion-R2}$, $T_{completion-R3}$, $T_{completion-R4}$, $T_{completion-R5}$ and $T_{completion-R6}$ representing the completion time for the total journey, Route1, Route2, Route3, Route4, Route5 and Route6 respectively. These variables are in seconds. The variable $T_{completion}$ was calculated for all 27 participants for both settings U1 and U2. The statistical summary of the $T_{completion}$ variables is shown in Table 8.8 (a) and (b). The second column, 'Total', refers to the total wayfinding journey. The mean of total completion time, $T_{completion-total}$, approximates the median for both setting U1 and U2. The distribution of $T_{completion-total}$ for setting U1 has a slight positive skew, with less for setting U2. Boxplots for $T_{completion-total}$ in each setting are given in Figure 8.14 (a) and (b). There is an outlier value (P23) in setting U1 and an outlier value (P05) in setting U2.

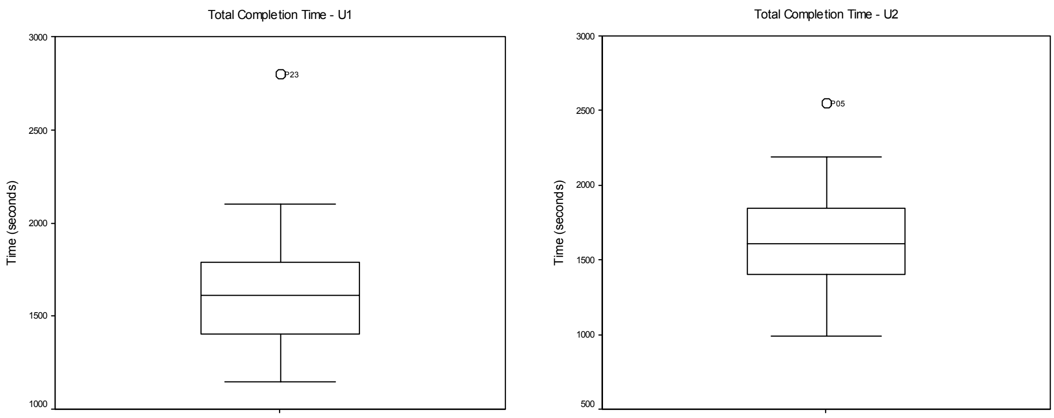
Urban Setting U1	**Total**	**Route1**	**Route2**	**Route3**	**Route4**	**Route5**	**Route6**
Mean	1629.07	176.81	275.63	241.04	405.67	243.93	286.00
Std. Error of Mean	67.26	10.67	28.06	21.18	19.55	12.55	10.75
Median	1610	165	257	209	399	222	271
Std. Deviation	349.48	55.46	145.78	110.07	101.58	65.19	55.87
Skewness	1.46	1.06	3.44	2.06	0.85	0.52	0.59
Kurtosis	3.62	0.87	14.95	4.41	0.32	-0.79	-0.79

(a)

Urban Setting U2	**Total**	**Route1**	**Route2**	**Route3**	**Route4**	**Route5**	**Route6**
Mean	1630.56	166.48	243.44	257.81	324.89	333.70	304.22
Std. Error of Mean	64.94	12.79	14.47	21.45	23.80	16.65	18.98
Median	1605	157	240	219	292	301	278
Std. Deviation	337.42	66.48	75.17	111.48	123.68	86.50	98.64
Skewness	0.55	1.16	0.74	1.31	0.45	0.68	1.21
Kurtosis	1.01	0.92	-0.07	1.64	-0.47	-0.12	0.78

(b)

Table 8.8 Statistical summary of $T_{completion}$ variables: (a) setting U1; (b) setting U2.



(a) (b)

Figure 8.14 Boxplots of $T_{completion\text{-}total}$ (n=27): (a) setting U1; (b) setting U2.

As with $D_{travelled\text{-}total}$, a test for normality was carried out on the variable $T_{completion\text{-}total}$ for settings U1 and U2. Table 8.9 gives the results of a Shapiro-Wilk test. For setting U1, the null hypothesis (H_0) of no difference can be rejected at $p < .05$; however, when the outlier value (P23) is removed then H_0 cannot be safely rejected and the data can be accepted as normally distributed. For setting U2, the H_0 cannot be rejected safely and the data can be accepted as normally distributed.

Urban Setting U1	Statistic	df	Sig.	***Urban Setting U2***	Statistic	df	Sig.
Tcompletion-total	0.9	27	0.015	Tcompletion-total	0.973	27	0.681
Tcompletion-total less P23	0.967	26	0.545				

Table 8.9 Normality test for the total completion time

The completion time for each route in both setting U1 and U2 were also calculated. From the statistical summary (Table 8.8 (a) and (b)) and the boxplots (Figure 8.15 (a) and (b)) for these variables ($T_{completion\text{-}R1}$, $T_{completion\text{-}R2}$, $T_{completion\text{-}R3}$, $T_{completion\text{-}R4}$, $T_{completion\text{-}R5}$ and $T_{completion\text{-}R6}$), considerable variation in the distributions can be observed. The distributions of the variables $T_{completion}$ are highly skewed for some of routes. The median values are a good reflection of the relative completion time for reaching successive destinations. The range of values for each boxplot reflects individual completion times, showing that some participants took longer than others. There are a good few numbers of outlier/extreme values on some of the routes, such as Route3 in setting U1. This illustrates that some participants took considerably longer to complete this wayfinding task than others. Some routes have a wider spread but no outliers, such as Route4 in setting U2. However, there is no single individual who consistently takes longer or shorter times to complete every one of the routes. Thus the variable $T_{completion}$ appears to be influenced by the participant difficulty in determining routes between successive destinations, and the time taken for accessing and assimilating information through the PDA.

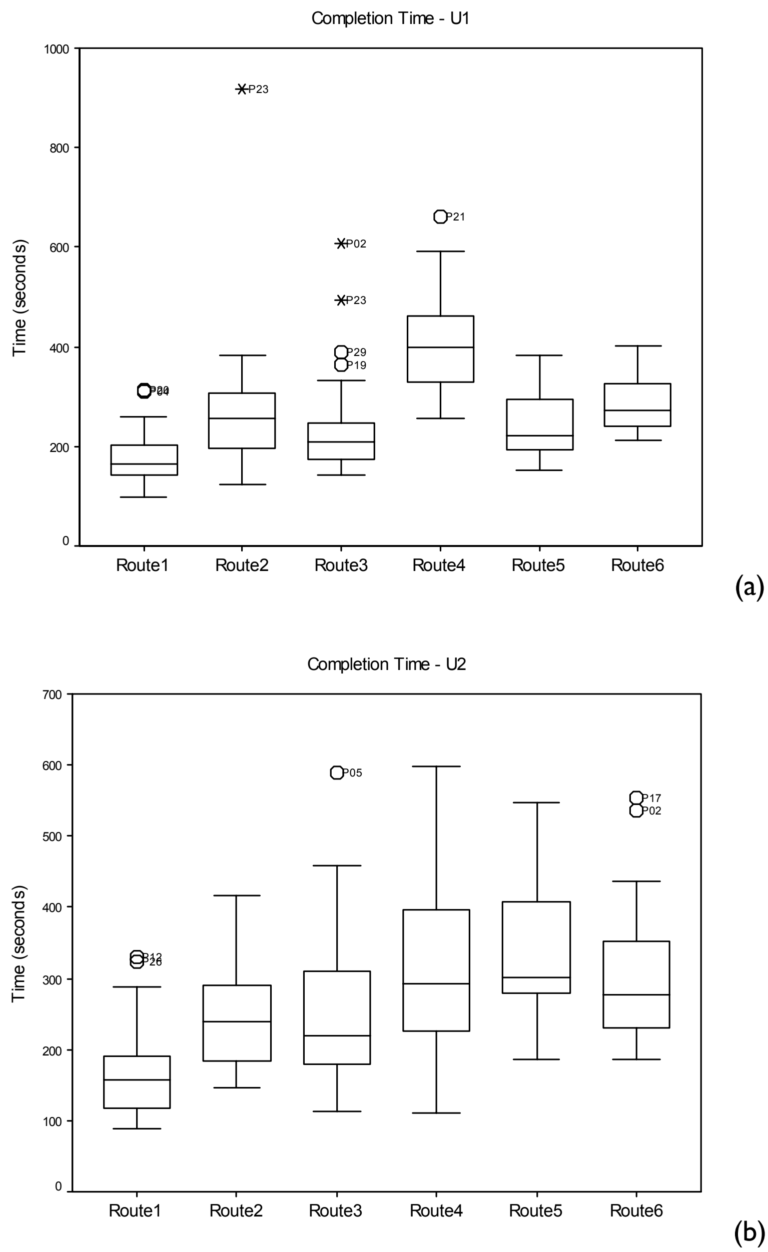


Figure 8.15 Completion time for each route (n=27): (a) setting U1; (b) setting U2

In order to establish any significant difference arising from the sequence in which the settings were used, the variable $T_{completion-total}$ was also tested in the same way as discussed in §8.4.2 for the variable $D_{travelled-total}$. For setting U1, 14 participants were required to take U1 as their first setting in which to start their wayfinding tasks, and the other 13 participants took U1 as their second setting. The result of a Mann-Whitney U test is: $U(14, 13) = 46.00$, $p = 0.029$. Thus the H_0 of no significant difference can be rejected at $p < 0.05$ level, giving a significant difference in $T_{completion\text{-}total}$ between these two groups of participants. For setting U2, 13 participants took U2 as their first setting, and another 14 participants took U2 as their second setting. The result, U(13, 14) = 57.00, $p = 0.105$, shows that H_0 cannot be rejected. Thus, for setting U2 there is no significant difference in $T_{completion\text{-}total}$ between the two groups. However, with regard to the statistically significant result for U1 , only Route6 is significantly different at $p < 0.05$ (Table 8.10). For individual routes in setting U2, there is a significant difference at $p< 0.05$ in Route4 only. The result for $T_{completion\text{-}total}$ in setting U1 is clearly an effect of aggregation. Therefore, on the basis of this analysis of each of the two complete routes, it seems reasonable to conclude that the overall differences in the variable $T_{completion}$, particularly on individual tasks, do not show any consistently significant change resulting from their experience in their wayfinding in the first setting.

Urban Setting U1	**Route1**	**Route2**	**Route3**	**Route4**	**Route5**	**Route6**
Mann-Whitney U	69	51.5	52.5	85	56	49
Asymp. Sig. (2-tailed)	0.286	0.055	0.062	0.771	0.089	0.041
Exact Sig. [2*(1-tailed Sig.)]	0.302	0.054	0.061	0.793	0.094	0.043

Urban Setting U2	**Route1**	**Route2**	**Route3**	**Route4**	**Route5**	**Route6**
Mann-Whitney U	67	71	84	50.5	68.5	81
Asymp. Sig. (2-tailed)	0.244	0.332	0.734	0.049	0.275	0.627
Exact Sig. [2*(1-tailed Sig.)]	0.259	0.35	0.756	0.048	0.28	0.65

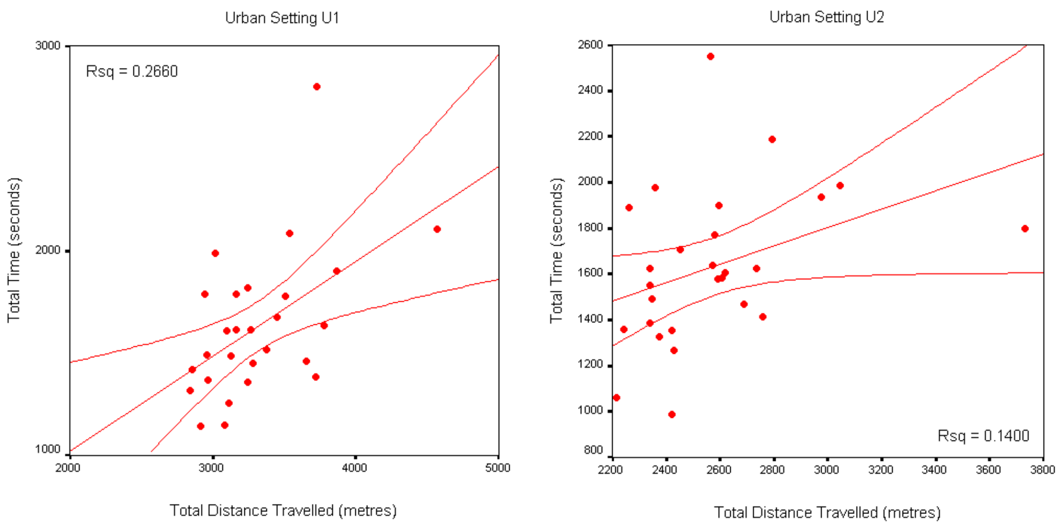
Table 8.10 Significance test for differences in sequence by route for settings U1 and U2.

8.4.4 Time and Distance

The completion time and the distance travelled are two obvious variables for assessing wayfinding task performance. The correlations between these two variables could vary according to the differences in routes travelled, the time spent for accessing information for assisting wayfinding, the stopping time for either observing or hesitating, and so on. Table 8.11 shows the correlation between $T_{completion\text{-}total}$ and $D_{travelled\text{-}total}$ for all wayfinding tasks (from a starting point and back to the starting point) in both setting U1 and U2. The correlations are: 0.518 (significant at $p < .05$ and also $p < .01$ for setting U1 and 0.465 significant at $p < .05$ level for setting U2). The scatter diagrams (Figure 8.16) also illustrate the relationship between the variables $T_{completion\text{-}total}$ and $D_{travelled\text{-}total}$. However, the low R^2 for both settings shows that total distanced travelled does not explain sufficient variance in the total time taken, perhaps counter to what one might expect. Thus from the scatter diagrams, it is easy to pick out participants who have travelled further than average and yet covered the distance relatively quickly and others who have travelled no further than average yet covered the distance relatively slowly. This relationship for setting U2 (Figure 8.16(b)) is still weaker than that for setting U1 (Figure8.16(b)).

Urban Setting U1			$T_{completion-total}$
Spearman's rho	$D_{travelled-total}$	Correlation Coefficient	0.518
		Sig. (2-tailed)	0.006
		N	27
Urban Setting U2			$T_{completion-total}$
Spearman's rho	$D_{travelled-total}$	Correlation Coefficient	0.465
		Sig. (2-tailed)	0.015
		N	27

Table 8.11 Correlation coefficients between distance travelled and completion time in settings U1 and U2.



(a) (b)

Figure 8.16 Regression of total completion time again total distance travelled with 95% confidence limits: (a) setting U1; (b) setting U2.

The relationship between $T_{completion}$ and $D_{travelled}$ was further studied for each of the six wayfinding tasks (Route1 to Route6). The scatter diagrams were plotted with same scale on x, y axis throughout for visual comparison (Figure 8.17 and Figure 8.18). Firstly, what can be observed is that the nature of the relationship between $T_{completion}$ and $D_{travelled}$ for each route varies. For setting U1 (Figure 8.17), some routes have a higher R^2 between variables $T_{completion}$ and $D_{travelled}$ than others. For example, the R^2 for Route3 (Figure 8.17(c)) is the highest (though influenced by the positive leverage effect of an outlier), and the lowest is R^2 shown for Route6 in Figure 8.17(f), in which most of participants have very similar values on the distanced travelled but considerable variation in time taken. This phenomenon can also be observed in setting U2 (Figure 8.18). For instance, for both Route1 and Route6, the distance travelled, $D_{travelled}$, varies little yet completion times $T_{completion}$ are highly variable (particular in Route6, ignoring the outlier). When considered in isolation, the variables $T_{completion}$ and $D_{travelled}$ for Route3 and Route4 have stronger correlations than the other routes. These results may be manifestations of the variable complexity in the layout of the chosen routes, the variable time necessary for information access, and variation in any time spent whilst lost or confused. Secondly, the relationship between the two variables $T_{completion}$ and $D_{travelled}$ in each route shows differences when comparing settings U1 with U2. For example, the relations shown in Route6 for both settings (Figure 8.17(f) and Figure 8.18(f)) indicate that there is greater diversity in completion time, $T_{completion}$, for the participants when in setting U2 than in U1. In addition, the outlier points, such as the ones shown in Figure 8.17 (b), (c), (d), (f) and Figure 8.18(f), could seriously affect the measures of central tendency. Therefore, the regression lines and their R^2 values are sometimes biased as a result, though the scatter diagrams can still allow the more detailed pattern to be visualised.

The correlation of $T_{completion-total}$ and $D_{travelled-total}$ for the aggregated routes in U1 and U2 does not appear to be a good reflection of the relationship for each route (the individual wayfinding tasks). From the relationship between the completion time and distance travelled, it appears that the perceived complexity and different spatial layout of each route affects participant ability in wayfinding. Furthermore, for the similar distance travelled, the variable $T_{completion}$ can differ between different routes and does not form the expected strong relationship of longer time for longer distance travelled. This may arise because a certain proportion of the time is being used to plan each route and otherwise accessing and assimilating information from the PDA. The time spent on accessing information via the PDA will be investigated in the next Section.

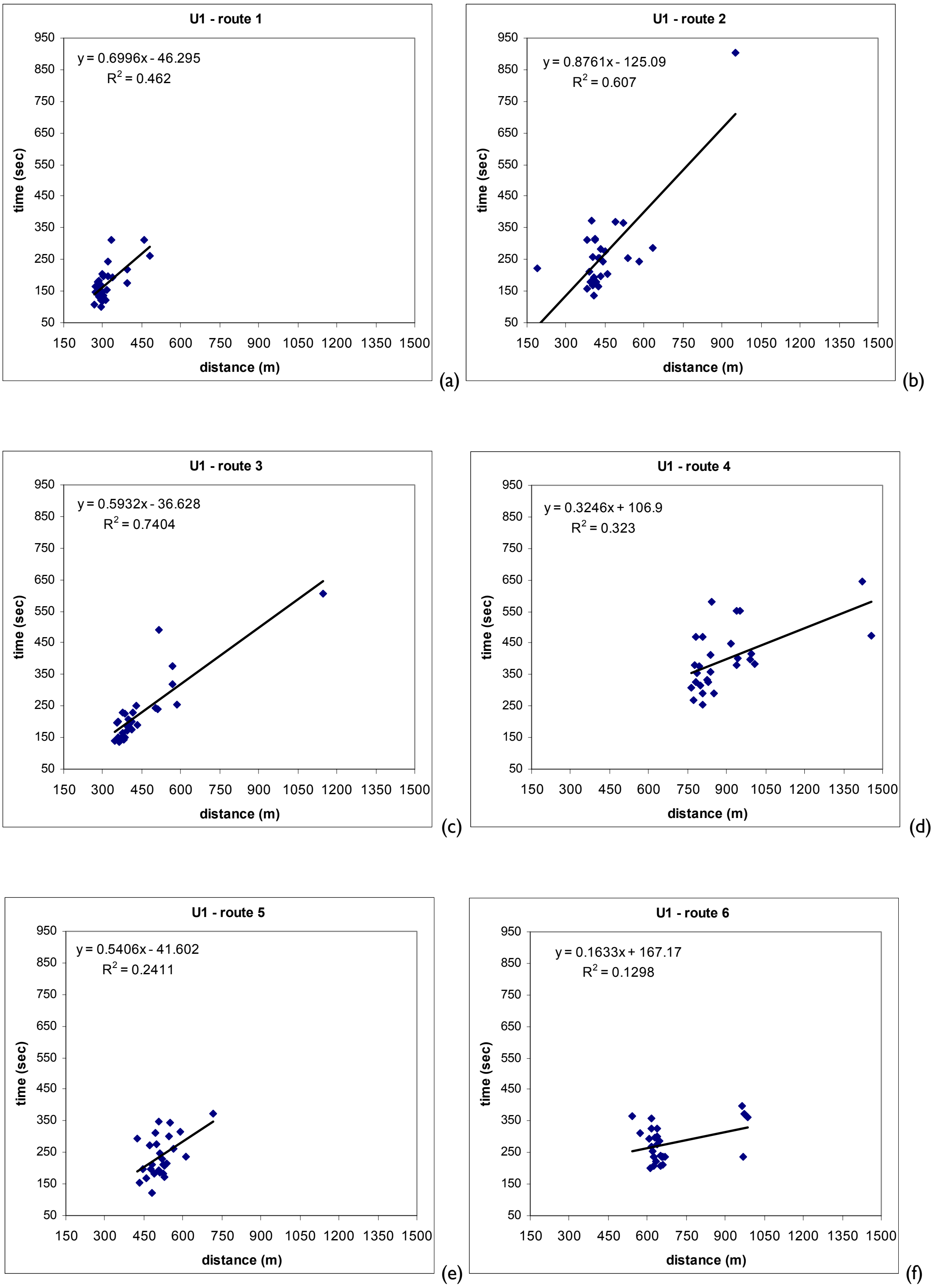


Figure 8.17 Time against distance for six routes in setting U1.

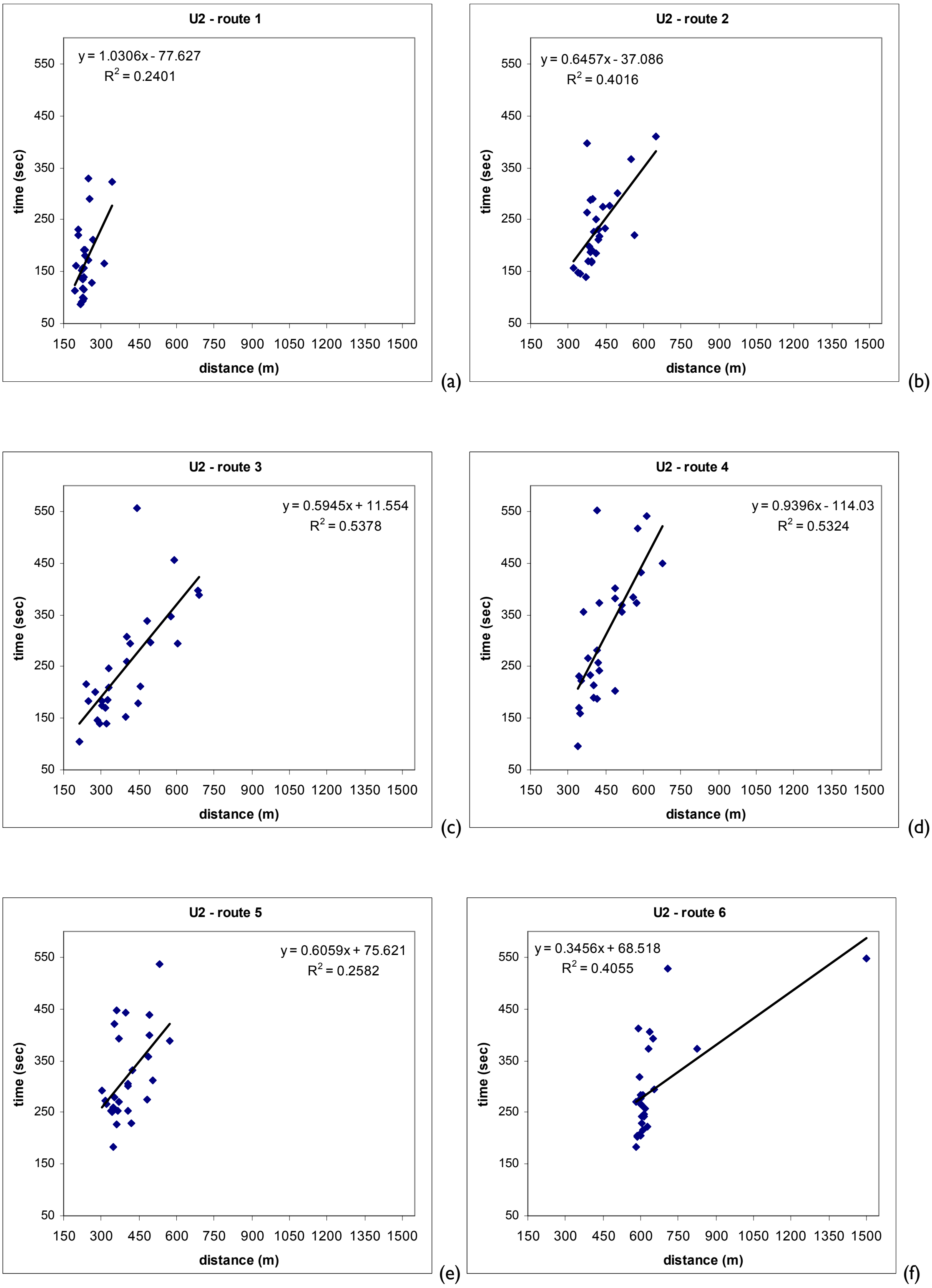


Figure 8.18 Time against distance for six routes in setting U2.

Discussion: In Section 8.4, the distance travelled $D_{travelled}$ and the time taken, $T_{completion}$, are two important factors in performing wayfinding tasks. Both of these variables can reflect the routes taken. The upper speed at which participants can 'walk' through the settings is limited and therefore differences in $T_{completion}$ are more likely to reflect time for accessing information, observing the environment, and time spent being lost or confused. From the observation made of the participants, some do nevertheless access information on the 'fly'. The values of these two variables for all 27 participants in both settings were calculated from the 54 positional track data files discussed in §8.1.1.

For counterbalancing the sequences by which the settings were used in wayfinding experiments, half of the participants started the first set of wayfinding tasks in setting U1, whilst the other half started in setting U2. The test for any significant differences between these two groups was carried out on both sets of variables $D_{travelled}$ and $T_{completion}$ for both settings. The overall results showed that there is no consistent significant difference between these two groups of participants regarding the wayfinding performance as measured by distance travelled and time taken. Thus, for both settings, the sequence in which the settings were used has had no significant influence on the distance travelled and time needed to complete the tasks. Therefore, no significant change arises in learning from the experience of wayfinding in their first setting. In the following analysis, these two groups of participants will therefore be treated as a single group. The apparent lack of any further learning from the wayfinding in the first setting may result from sufficient training in the pre-experiment familiarisation for participants prior to the main experiments (§7.4). This is a positive sign as the data collected reflects participants' unaltered abilities applied to both settings. This is not to argue against any longer term learning effect, but this is beyond the scope of this research. This aspect will be further investigated for PDA information usage time in §8.5.3.

The spatial distribution of the wayfinding tracks taken by all 27 participants is illustrated in two intensity maps (Figure 8.10 for U1, Figure 8.11 for setting U2). Diversity of routes taken for each of the tasks and the different intensities of positional points strongly indicates that the characteristics of spatial locations have a major influence on wayfinding behaviour. The distributions of variables $D_{travelled}$ shown in Figure 8.13 and $T_{completion}$ in Figure 8.15 exhibit differences for each route and appear to vary according to the perceived complexity of wayfinding between successive destinations in the two settings, and the time used for accessing and using information via the PDA. Additionally, the scatter diagrams shown in Figure 8.17 and Figure 8.18 demonstrate the variety of relationships between $D_{travelled}$ and $T_{completion}$ amongst the routes. This also suggests that different wayfinding behaviour is characteristic in areas of different urban morphology (i.e. setting U1 versus setting U2) and in differences in adopting routes which have a range of spatial layouts (route geometry). This will be analysed further in the next Section with respect to the accessing and use of spatial information during wayfinding.

Also illustrated in the intensity maps is that the starting points of each route have high intensities in the figures, which could be explained by more time being spent at these locations prior to moving on. Such periods will have been used to plan the wayfinding strategy. This use of time is particularly noticeable in the scatter diagrams in Figure 8.17(a) and Figure 8.18(a) for Route1 in setting U1 and setting U2 respectively. The descriptive summaries of $T_{completion}$ suggest very similar distances travelled by each participant, but differences in time used for planning (as well as more general familiarisation with the setting) amongst the participants. This period of 'planning time', therefore, should be extracted out from the completion time, $T_{completion}$, to form a new variable which can be studied (see §8.5.4).

The ability to study participants' wayfinding behaviours at these different levels of detail and from different aspects is as a consequence of the data collection methods adopted for carrying out the experiments. In order to examine the interaction between the individual, mobile device and environment, the variables already analysed can be studied alongside the information accessed through the PDA.

8.5 PDA spatial information usage

The access and usage of spatial information via the PDA was collected during participants' wayfinding. In this Section, a range of variables are derived from the integrated data sets to describe individual spatial information usage through the PDA (e.g. frequency of accessing information, time spent on PDA usage, planning time for wayfinding tasks). These variables are then analysed in relation to the spatial layout of the environment in which the wayfinding activities took place as represented in the two urban settings. The term 'PDA information' used in this and subsequent Sections generally refers to all the spatial information accessed through the PDA such as the maps with overview layout of the area, the maps with detailed zoom-in and route descriptions. Also the term 'overview map' refers to the sketch map with correct scaled street layout of the area and selectable landmarks and road names (see §6.2.2), whilst 'detailed map' refers to the zoom-in maps of partial areas (also see §6.2.2). Although the route information was available in both voice and text formats, few participants used voice and therefore both types of information have been grouped as 'route' information. An advantage of the VR environment over 'real world' studies, as will be clear in the following

Sections, is that it is possible to ascertain exactly where, when and for how long participants consult external sources of information, specifically the sources available through the PDA.

8.5.1 Spatial distribution of PDA information access

The spatial distribution of PDA information access can be mapped by using the integrated data sets discussed in §8.1.1. The points where participants accessed and studied PDA information were extracted from these integrated data sets containing positional point data and PDA information usage data. A new data set was then created combining the 27 integrated data tables in setting U1. There are a total of 1,252 points. The intensity map (Figure 8.19) for setting U1 was created in ArcGIS, using kernel density estimation with a 1 metre grid cell and a 10 metre bandwidth. The starting/finishing point and five destinations (D1 to D5) are also shown on the intensity map along with all the road centre lines of the area. Firstly, it clearly demonstrates that the PDA information was frequently used for assisting wayfinding along all routes travelled by participants. The information was accessed and used more frequently on some routes than on others. For instance, the segments of boundary roads in the southern half of the area have lower intensities than the segments of inner roads. This could have resulted from the fact that one side of these boundary roads is lined with homogeneous high trees or hedges (see images in Appendix III), which only gave participants the option of turning into the built-up area for their wayfinding tasks, thus necessitating less frequent recourse to the PDA for information. Secondly, most of higher intensity locations were at the start point of the whole wayfinding experiment and at the destinations of each separate task (which also marked the starting points for the next task). These were usually locations where participants accessed information, in order to plan and determine how they were going to reach the next destination. Thus the greater time spent on these locations led to more positional points being recorded at these locations. However, the intensities at the start points for some routes are higher than others. For example, the densities at D1 and at D2 are higher than those at D4 and at D5. This could have been influenced by the anticipated complexity of the routes to be encountered during the subsequent wayfinding task.

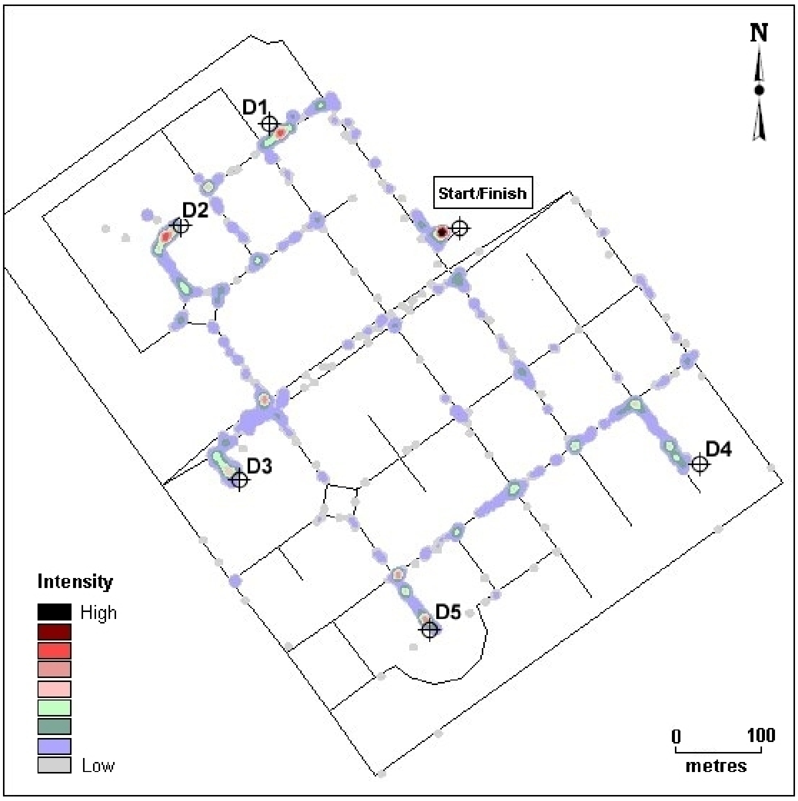


Figure 8.19 Intensity map (number of recorded points per metre²) of points where PDA information is used - setting U1.

For the setting U2, the same procedure for creating the intensity map was followed using the total of 1,508 position points where PDA information was accessed and studied in setting U2. The intensity map is overlaid on the central road lines of the area with marked start/finish points and the five destination points D1 to D5. Here too the frequent usage of PDA information is evident along all of the travelled routes. All of the starting points of individual wayfinding task are locations with higher intensities, which is consistent with the pattern observed in setting U1. However, in this setting, each of the start points (D1 and D5) demonstrates higher intensities than other locations, more so than in setting U1. This could arise because of the more irregular spatial layout of the area in setting U2 compared with setting U1. The start point for the whole wayfinding experiment in this setting is the location with the highest intensity, correspondingly with the equivalent start point in setting U1. In addition, both sides of the boundary roads in this setting are lined with urban style houses (see images shown in Appendix III). This is different from the boundary road environment in setting U1 (discussed above). This has resulted in a different pattern of PDA information usage along those boundary roads travelled by participants in this setting.

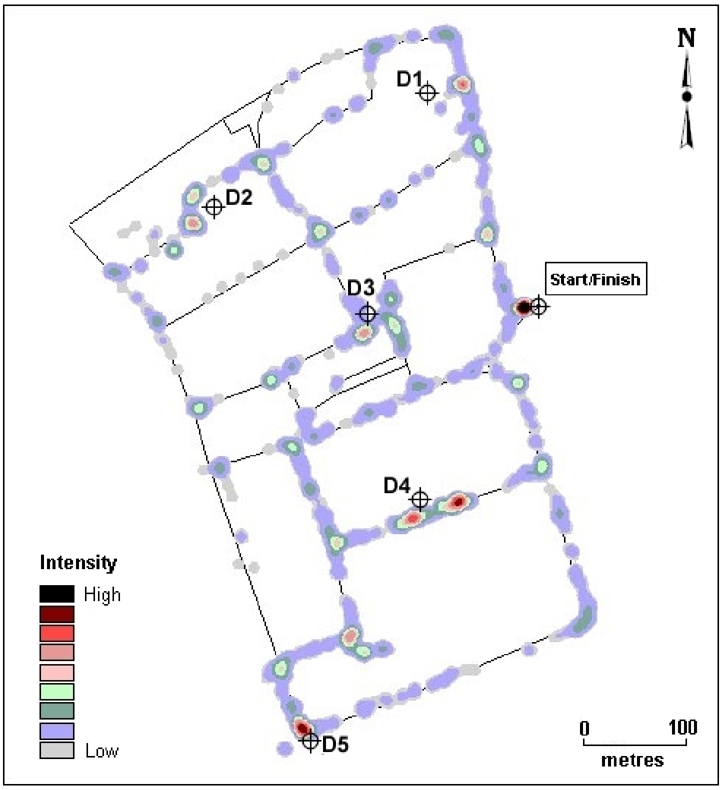


Figure 8.20 Intensity map (per metre²) of points where PDA information is used - setting U2.

8.5.2 Frequency of PDA information access

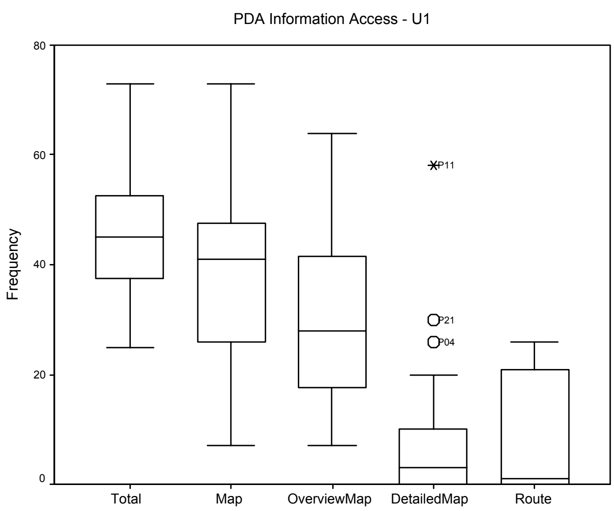
The frequency of PDA information access as a variable, denoted as $F_{pda\text{-}total}$, refers to the numbers of times that the information is accessed using the PDA. This access is both that achieved by means of clicking the PDA for new pages and also referring again to the current page on the PDA. The variable $F_{pda\text{-}total}$ was derived from the action data set (Table 8.1). The variable $F_{pda\text{-}total}$ depicts the frequency of PDA information access for all information. Then a further list of specific frequency variables were derived for accessing all types of maps ($F_{pda\text{-}map}$), accessing overview map only ($F_{pda\text{-}o\_map}$), accessing detailed map only ($F_{pda\text{-}d\_map}$) and accessing route information ($F_{pda\text{-}route}$). The statistical summaries (Table 8.12) show the mean values with the standard deviation for all these frequency variables for both settings U1 and U2. Median value and skewness, kurtosis of the distribution of these variables are also shown in the Table. The boxplots (Figure 21) illustrate these distributions with outlier/extreme values marked.

Urban Setting U1	**Total**	**Map**	**OverviewMap**	**DetailedMap**	**Route**
Mean	46.37	38.19	29.70	8.48	8.63
Std. Error of Mean	2.26	3.20	3.09	2.55	2.09
Median	45	41	28	3	1
Std. Deviation	11.72	16.62	16.05	13.23	10.88
Skewness	0.54	0.08	0.53	2.41	0.64
Kurtosis	-0.17	-0.50	-0.41	6.80	-1.52

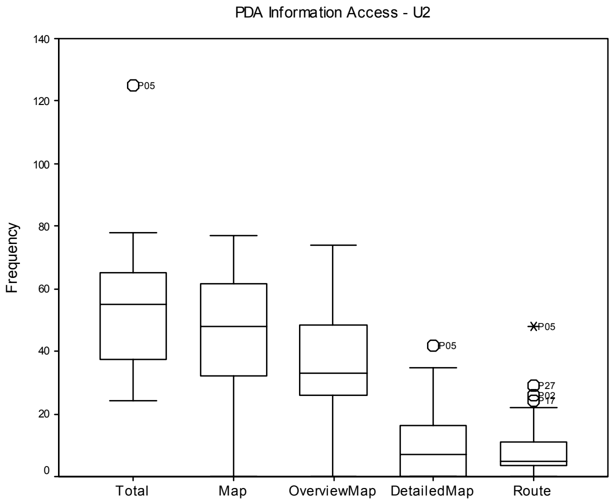
Urban Setting U2	**Total**	**Map**	**OverviewMap**	**DetailedMap**	**Route**
Mean	55.74	45.96	35.48	10.48	9.78
Std. Error of Mean	3.99	3.96	3.68	2.32	2.18
Median	55	48	33	7	5
Std. Deviation	20.72	20.57	19.10	12.06	11.32
Skewness	1.26	-0.38	0.32	1.24	1.96
Kurtosis	3.47	-0.67	-0.40	0.69	3.88

Table 8.12 Statistical summary of the frequency variables (F_{pda}) for setting U1 and U2 where Total is for $F_{pda\text{-}total}$, Map is for $F_{pda\text{-}map}$ and so on.

The average and median values in setting U2 are higher than those in setting U1 which suggests that participants found setting U2 to be the more challenging to navigate. Both the figures in Table 8.12 and the boxplots in Figure 8.21 (a) and (b) show that the distribution of the variables $F_{pda\text{-}d\_map}$ (the frequency of accessing detailed map information) and $F_{pda\text{-}route}$ (the frequency of accessing route information) are different from the distribution of the aggregated frequency variable $F_{pda\text{-}total}$ for both settings. There are a number of outlier/extreme values for these two variables. These differences can also be found between these two variables and the variable $F_{pda\text{-}map}$ (the frequency of accessing total map information) and $F_{pda\text{-}o\_map}$ (the frequency of accessing overview map information). The large spread in the distribution of the variables $F_{pda\text{-}route}$ for settings U1 and U2 is evident in both the high standard deviations (Table 8.12) and the boxplots (Figure 8.21(a) and (b)). Also from the boxplots, it can be seen that there is a clear preference for map information as compared with route information.



(a)



(b)

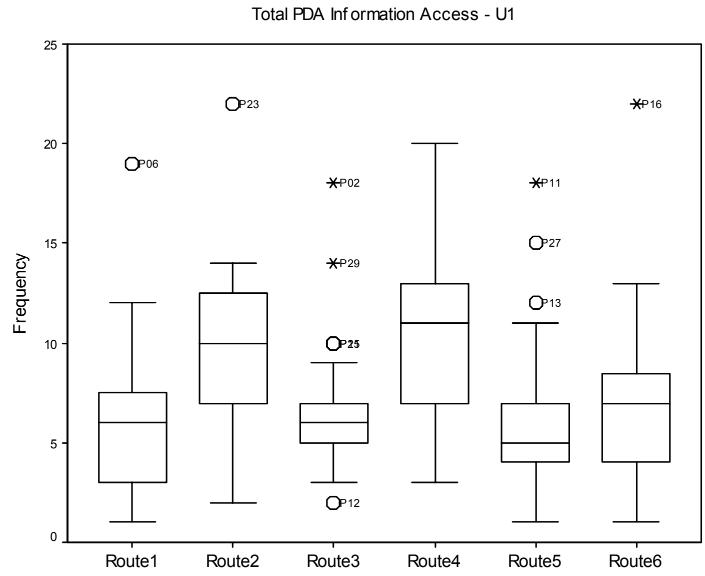
Figure 8.21 Frequency of PDA information accessed (n=27):
(a) setting U1; (b) setting U2.

The frequency variable for total information accessed, $F_{pda-total}$, was further investigated for each individual task (Route1 to Route6). Table 8.13 shows the statistical summaries of the variable for each route, while Figure 8.22 (a) and (b) illustrates the distribution of these frequency variables for setting U1 and setting U2 respectively. There is considerable variety between the routes with contrasting distributions. This perhaps reflects the relative complexity of each of the routes and the consequent need for consulting the PDA for information. Setting U2 has consistently higher standard deviations suggesting that there is greater range of behaviours given the irregular layout of this setting. Route4 in setting U1 has the highest overall frequency of PDA information access. This corresponds to the time-distance relation shown in Figure 8.17 (d). Although this is the longest route in the U1 experiment, the scatter diagram illustrates how, despite the similar route lengths travelled by participants, proportionately more time was spent on the task (with considerable spread) and is reflected in the higher frequency of PDA access. Overall these results of frequency of PDA access appear to be consistent with the results analysed from completion time $T_{completion}$ and distance travelled $D_{travelled}$.

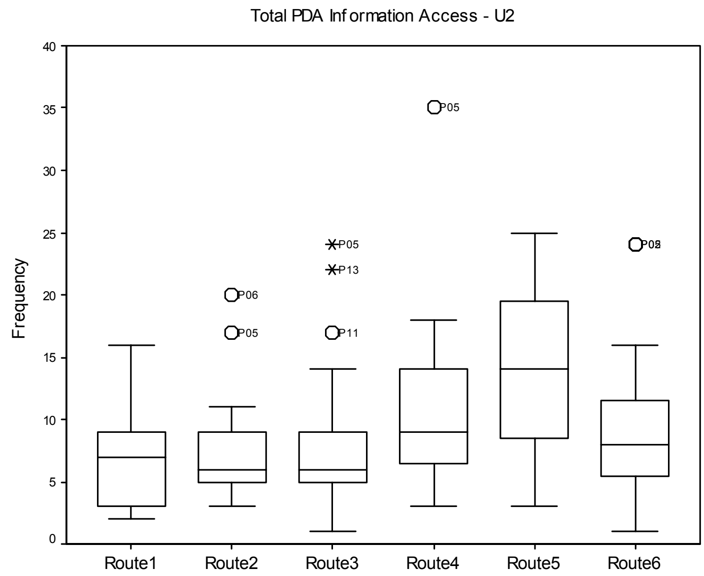
For each of the six routes (Route1 to Route6) in both settings U1 and U2, the statistical summaries and boxplots for each frequency variable, $F_{pda-map}$, F_{pda-o_map}, F_{pda-d_map} and $F_{pda-route}$ are shown for reference in Appendix VI.

Urban Setting U1	Total	Route1	Route2	Route3	Route4	Route5	Route6
Mean	46.37	6.00	9.63	6.74	10.63	6.37	7.00
Std. Error of Mean	2.26	0.74	0.77	0.68	0.87	0.77	0.80
Median	45	6	9	6	11	5	7
Std. Deviation	11.72	3.84	4.02	3.51	4.50	3.99	4.15
Skewness	0.54	1.48	0.91	1.57	0.40	1.40	1.83
Kurtosis	-0.17	3.84	2.17	3.19	-0.06	1.86	5.60
Urban Setting U2	**Total**	**Route1**	**Route2**	**Route3**	**Route4**	**Route5**	**Route6**
Mean	55.74	6.70	7.11	8.22	10.89	13.81	9.00
Std. Error of Mean	3.99	0.79	0.78	1.06	1.28	1.28	1.13
Median	55	7	6	6	9	14	8
Std. Deviation	20.72	4.09	4.05	5.50	6.64	6.63	5.88
Skewness	1.26	0.79	1.80	1.63	1.85	0.03	1.15
Kurtosis	3.47	-0.12	3.61	2.51	5.60	-1.15	1.49

Table 8.13 Statistical summary of the variable $F_{pda\text{-}total}$ (the frequency of PDA information accessed) in total and for each route.



(a)



(b)

Figure 8.22 The frequency of PDA information accessed for each route (n=27):
(a) setting U1; (b) setting U2.

The differences in the frequencies of PDA information access between the two groups of participants according to the sequence in which the settings were used have also been tested. The results of the Mann-Whitney U tests are as follows:

- for variable $F_{pda\text{-}total}$ in setting U1: U(14, 13) = 28.5, p = 0.002;
- for variable $F_{pda\text{-}total}$ in setting U2: U(13, 14) = 79.5, p = 0.583.

Thus the H_0 of no significant difference can be rejected at $p < 0.05$ level for setting U1, giving a significant difference in $F_{pda\text{-}total}$ between these two groups of participants. The H_0 of no significant difference cannot be rejected at $p < 0.05$ level for setting U2. By further analysing the differences in each of the six routes (Table 8.14), the majority of routes show that there is no significant difference between the two groups, only one route shows the significant difference at the $p < 0.05$ level. Route 5 (from D4 to D5) in setting U1 is a relatively straightforward wayfinding task (distance travelled and time taken both have a relatively low standard deviation). This route configuration may allow a significant learning effect to be detected in a short-term experiment. Nevertheless, no significant effect can be detected for the other routes. The significant difference for the experiment may be overly influenced by aggregation effects. Therefore, on the basis of this more detailed analysis of each route, the overall differences in $F_{pda\text{-}total}$ do not show any consistently significant change resulting from their experience in their wayfinding in the first setting.

Urban Setting U1	**Route1**	**Route2**	**Route3**	**Route4**	**Route5**	**Route6**
Mann-Whitney U	68	64.5	53.5	87.5	33.5	51.5
Asymp. Sig. (2-tailed)	0.261	0.196	0.061	0.864	0.015	0.056
Exact Sig. [2*(1-tailed Sig.)]	0.28	0.202	0.063	0.867	0.014	0.055

Urban Setting U2	**Route1**	**Route2**	**Route3**	**Route4**	**Route5**	**Route6**
Mann-Whitney U	71	72	68	63	68.5	73
Asymp. Sig. (2-tailed)	0.332	0.356	0.264	0.174	0.275	0.382
Exact Sig. [2*(1-tailed Sig.)]	0.35	0.375	0.28	0.185	0.28	0.402

Table 8.14 Significance test for differences in sequence by individual route.

For urban setting U1 and U2, the mean and median values of the variable $F_{pda\text{-}total}$, as shown in Table 8.11, are higher in setting U2 than in setting U1. This suggests that participants found setting U2 needed more information to complete tasks. However, there is no significant difference from the result of a Man-Whitney U Test:

Total PDA frequency U1 and U2: Mann-Whitney U test: U(27, 27) = 265, p = 0.085;

H_0 cannot be rejected at $p < 0.05$ and there is no significant difference between total PDA frequency between U1 and U2. This result may seem counter-intuitive. However, this may reflect that, in general, the PDA was accessed frequently on all routes travelled despite the two different urban layouts (Figures 8.19 and 8.20). The frequency of usage does not reflect the time used in studying information and the PDA can easily be consulted to re-confirm routes being taken and thereby increasing the frequency of usage. In the next section when the time span of PDA information usage is analysed, the result does show a significant difference between the two settings.

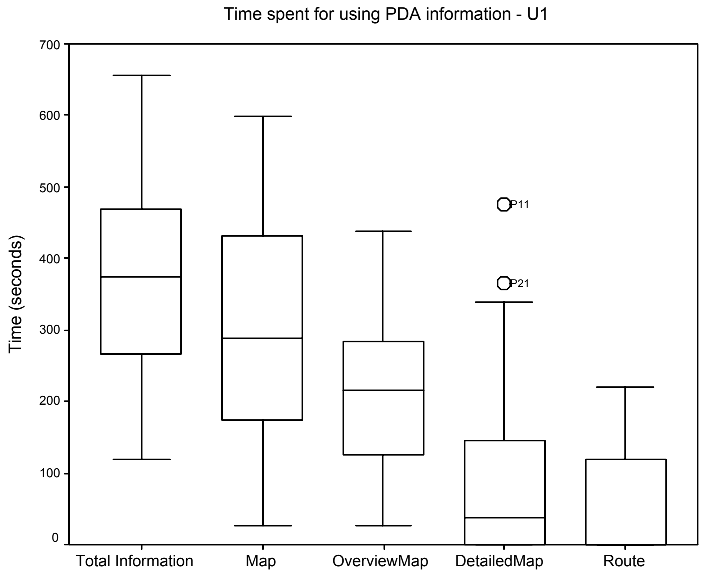
8.5.3 Time spent for PDA information usage

Although the frequency of PDA information accessed provides an important factor in the use of spatial information during the wayfinding tasks, the time spent studying PDA information reflects the different lengths of time used by participants to access and assimilate the information. Furthermore, different lengths of time might be used in studying different types of spatial information (e.g. overview map of the area layout, detailed zoom-in map, route information). The variable of the total time spent for PDA information usage is denoted as $T_{pda\text{-}total}$, comprising the time spent for using all the information through the PDA. The variable $T_{pda\text{-}total}$ was derived from the action data set (Table 8.1). Then some further specific time variables were derived for: using all types of maps ($T_{pda\text{-}map}$), using overview map only ($T_{pda\text{-}o\_map}$), using detailed map only ($T_{pda\text{-}d\_map}$) and using route information ($T_{pda\text{-}route}$). Shown in the statistical summary in Table 8.15, the mean and median values of time are generally higher in U2. When looking at the median time usage, for example, of detailed map $T_{pda\text{-}d\_map}$ it is nearly twice as high in setting U2; use of route information $T_{pda\text{-}route}$ is also correspondingly much higher. Boxplots of the distribution of these variables is shown in Figure 8.23 (a) and (b).

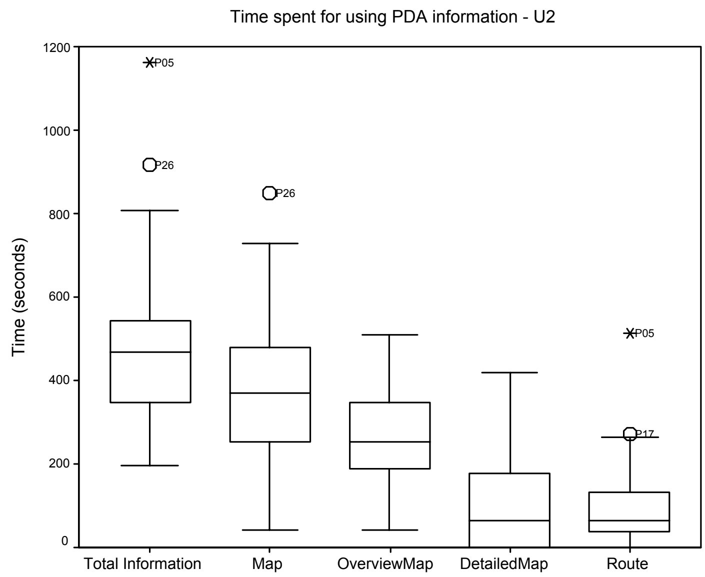
Urban Setting U1	**Total**	**Map**	**OverviewMap**	**DetailedMap**	**Route**
Mean	366.89	307.00	210.63	96.37	59.89
Std. Error of Mean	26.97	29.47	21.92	25.37	14.84
Median	374	289	215	38	0
Std. Deviation	140.15	153.14	113.92	131.81	77.09
Skewness	0.11	0.16	0.39	1.57	0.85
Kurtosis	-0.64	-0.88	-0.64	1.70	-0.80

Urban Setting U2	**Total**	**Map**	**OverviewMap**	**DetailedMap**	**Route**
Mean	487.48	382.00	268.48	113.52	105.48
Std. Error of Mean	39.92	35.48	24.47	24.58	21.96
Median	467	371	254	66	65
Std. Deviation	207.42	184.37	127.16	127.70	114.13
Skewness	1.67	0.52	0.09	1.19	2.11
Kurtosis	3.60	0.64	-0.55	0.50	5.15

Table 8.15 Statistical summary of the time (T_{pda}) variables for settings U1 and U2 where Total is for $T_{pda\text{-}total}$, Map is for $T_{pda\text{-}map}$ and so on.



(a)



(b)

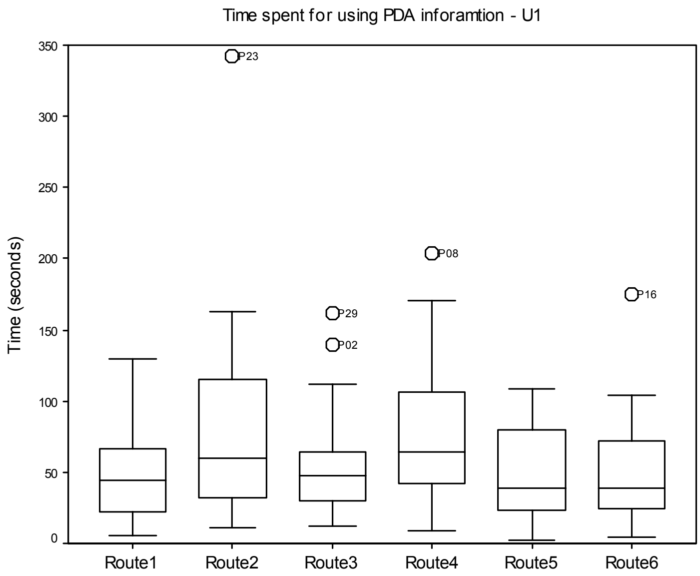
Figure 8.23 Frequency of PDA information accessed (n=27):
(a) setting U1; (b) setting U2.

The time variable for total information usage, $T_{pda\text{-}total}$, was further investigated for each individual task (Route1 to Route6). Table 8.16 shows the statistical summaries of the variable for each route, whilst Figure 8.24 (a) and (b) illustrates the distribution of these frequencies for setting U1 and setting U2 respectively. There is considerable variation between the routes with contrasting distributions. Route4 in setting U1 has the highest overall median time of PDA information access. This corresponds to the time-distance relation shown in Figure 8.17 (d). Route5 in setting U2 has the highest mean and median there, and this too corresponds to the relevant time-distance relation shown in Figure 8.18 (e). This reflects the complexity encountered during this particular task and forms a case study discussed in Section 8.7. Overall these results of the frequency of PDA access appear to be consistent with the results analysed from completion time $T_{completion}$ and distance travelled $D_{travelled}$.

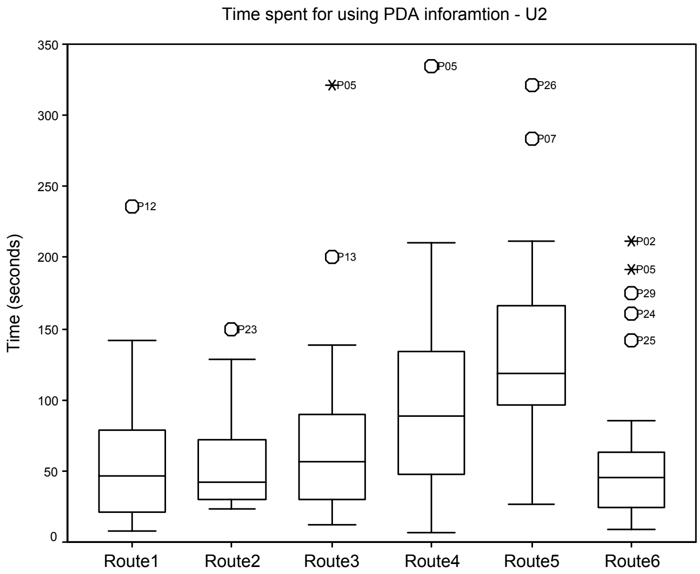
Urban Setting U1	**Total**	**Route1**	**Route2**	**Route3**	**Route4**	**Route5**	**Route6**
Mean	366.89	48.81	83.81	53.44	78.63	50.22	51.96
Std. Error of Mean	26.97	6.40	13.50	7.08	9.78	6.43	7.47
Median	374	44	60	48	64	39	39
Std. Deviation	140.15	33.23	70.17	36.79	50.84	33.41	38.81
Skewness	0.11	0.81	2.02	1.55	0.90	0.38	1.24
Kurtosis	-0.64	0.12	5.99	2.45	0.07	-1.32	2.40

Urban Setting U2	**Total**	**Route1**	**Route2**	**Route3**	**Route4**	**Route5**	**Route6**
Mean	487.48	60.67	58.04	73.70	97.70	134.44	62.93
Std. Error of Mean	39.92	10.26	6.63	13.06	13.48	12.98	11.37
Median	467	47	42	56	89	118	45
Std. Deviation	207.42	53.32	34.47	67.86	70.02	67.47	59.09
Skewness	1.67	1.65	1.14	2.20	1.53	1.06	1.46
Kurtosis	3.60	3.20	0.76	6.04	3.84	1.41	0.97

Table 8.16 Statistical summary of the variable $F_{pda\text{-}total}$ (the frequency of PDA information accessed) in total and for each route.



(a)



(b)

Figure 8.24 Time spent for PDA information usage on each route (n=27):
(a) setting U1; (b) setting U2.

For each of the six routes (Route1 to Route6) in both settings U1 and U2, the statistical summaries and boxplots for each frequency variable, $T_{pda\text{-}o\_map}$, $T_{pda\text{-}d\_map}$ and $T_{pda\text{-}route}$ are shown for reference in Appendix VII.

The differences in the time for PDA information access between the two groups of participants according to the sequence in which the settings were used are also tested. The results of the Mann-Whitney U tests are as follows:

- for variable $T_{pda\text{-}total}$ in setting U1: $U(14, 13) = 41.00$, $p = 0.014$;
- for variable $T_{pda\text{-}total}$ in setting U2: $U(13, 14) = 61.00$, $p = 0.155$.

Thus the H_0 of no significant difference can be rejected at $p < 0.05$ level for setting U1, giving a significant difference in $T_{pda\text{-}total}$ between these two groups of participants. The H_0 of no significant difference cannot be rejected at $p < 0.05$ level for setting U2. Further analysing the differences in each of the six routes (Table 8.17), the majority of routes show that there is no significant difference between the two groups, only Route5 in setting U1 shows a significant difference at $p < 0.05$ level. Therefore the overall differences do not show any consistently significant change in total time spent for PDA usage resulting from their experience in their wayfinding in the first setting.

Urban Setting U1	Route1	Route2	Route3	Route4	Route5	Route6
Mann-Whitney U	77.5	55	56	74	37	52
Asymp. Sig. (2-tailed)	0.512	0.081	0.089	0.409	0.009	0.053
Exact Sig. [2*(1-tailed Sig.)]	0.519	0.085	0.094	0.43	0.008	0.052

Urban Setting U2	Route1	Route2	Route3	Route4	Route5	Route6
Mann-Whitney U	71	72	68	63	68.5	73
Asymp. Sig. (2-tailed)	0.332	0.356	0.264	0.174	0.275	0.382
Exact Sig. [2*(1-tailed Sig.)]	0.35	0.375	0.28	0.185	0.28	0.402

Table 8.17 Significance test for differences in sequence by individual route.

The mean and median values of the variable $T_{pda\text{-}total}$, as shown in Table 8.15, are higher in setting U2 than in setting U1. This suggests that participants found setting U2 to be more challenging to navigate requiring more PDA time. The result of a Man-Whitney U Test:

Total PDA time U1 and U2: Mann-Whitney U test: U(27, 27) = 241.50, $p = 0.033$

shows that the null hypothesis (H_0) can be rejected at $p < 0.05$ with a significant difference between setting U1 and U2. It is therefore the length of time of PDA usage rather than the frequency of PDA usage which differentiates the two urban settings.

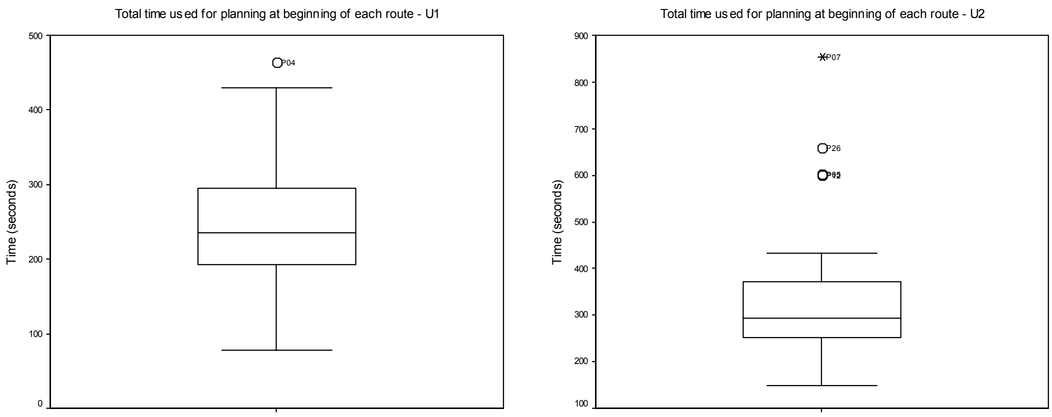
8.5.4 Task planning time

As discussed in §8.4.5 and illustrated in Figure 8.19 and 8.20, the time spent at the start points of each wayfinding task was identified as being used for planning and determining how to reach the next destination. This time could include the time for familiarising oneself with the environment and for accessing and studying the spatial information from the PDA. A new variable is consequently formed here for task planning time, denoted as T_{plan}, which is the time period elapsing while participants plan a new wayfinding task before they actually begin to navigate the chosen route. This variable was calculated from the integrated data sets described in §8.1.1. The variable T_{plan} can be measured as seven variables comprising: $T_{plan\text{-}total}$ for the whole wayfinding experiment; and $T_{plan\text{-}R1}$ to $T_{plan\text{-}R6}$ for each of the six routes. Table 8.18 presents a statistical summary for these seven variables with the column 'Total' for variable $T_{plan\text{-}total}$ and 'Route1' to 'Route6' for variables $T_{plan\text{-}R1}$ to $T_{plan\text{-}R6}$ respectively. The mean and median values of the total planning time ($T_{plan\text{-}total}$) in setting U2 is also higher than in setting U1. The boxplots in Figure 8.25 show the distribution of variable $T_{plan\text{-}total}$ in both settings, where the distribution for setting U2 has a positive skew.

Urban Setting U1	Total	Route1	Route2	Route3	Route4	Route5	Route6
Mean	247.30	43.41	43.93	38.81	43.63	34.81	42.70
Std. Error of Mean	16.80	5.41	6.12	4.36	5.62	4.13	5.34
Median	235	40	33	30	35	33	33
Std. Deviation	87.27	28.10	31.81	22.66	29.21	21.47	27.76
Skewness	0.62	0.73	1.48	1.14	1.20	1.34	1.08
Kurtosis	0.65	0.25	1.94	0.79	1.00	2.57	0.09

Urban Setting U2	Total	Route1	Route2	Route3	Route4	Route5	Route6
Mean	343.67	54.63	40.52	54.89	48.93	102.81	41.89
Std. Error of Mean	31.16	9.21	5.17	7.69	5.80	13.76	6.67
Median	294	42	37	42	45	91	29
Std. Deviation	161.93	47.88	26.84	39.98	30.15	71.52	34.68
Skewness	1.69	2.29	1.13	1.30	0.84	1.06	1.65
Kurtosis	2.93	6.25	1.37	1.14	-0.08	0.64	2.80

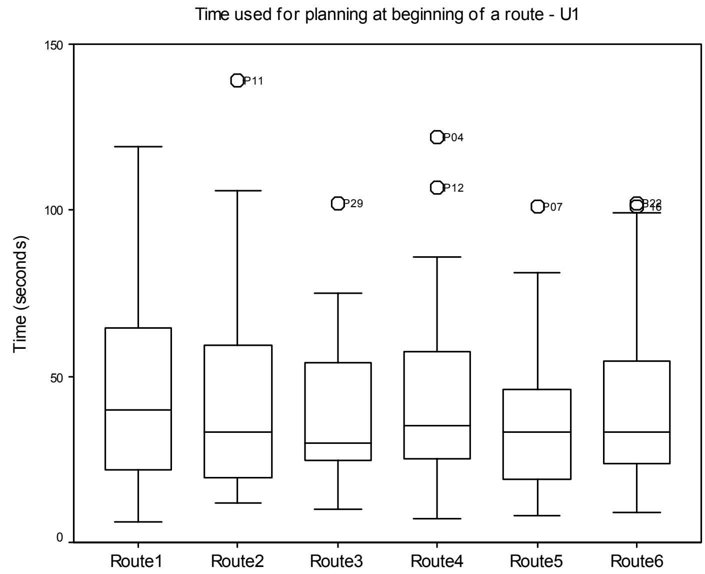
Table 8.18 Planning time for total wayfinding experiment and for the six routes



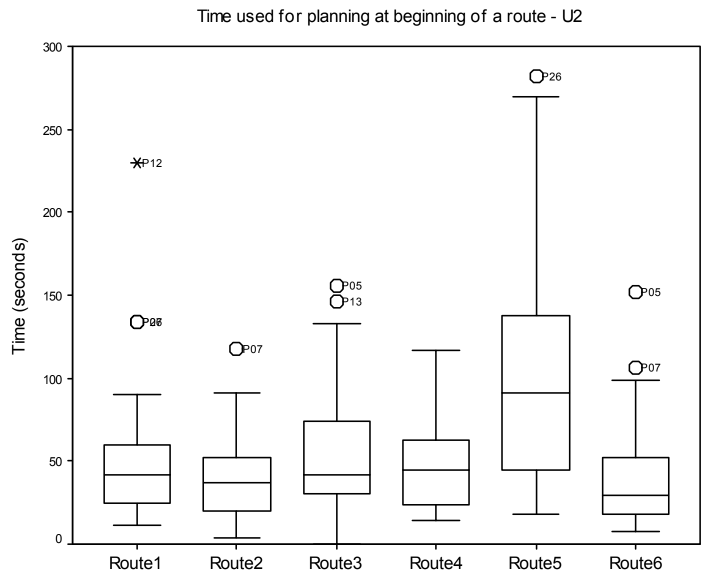
(a) (b)

Figure 8.25 Total planning time ($T_{plan\text{-}total}$): (a) setting U1; (b) setting U2.

The distributions of the variable $T_{plan\text{-}R1}$ to $T_{plan\text{-}R6}$ for each route in both settings are shown in Figure 8.26. The variability of the distributions is evident across the six routes in both settings. However, the planning time variables in setting U1 have less variability than in setting U2. This could indicate that participants perceived different levels of complexity in the urban morphology of the two settings using the planning time variables.



(a)



(b)

Figure 8.26 Planning time for each route: (a) setting U1; (b) setting U2.

For setting U2, the mean and median of the planning time variable $T_{plan\text{-}total}$ are higher than in setting U1 (Table 8.15). This difference is shown to be significant from the result of the Mann-Whitney U test: $U(27, 27) = 212.00$, $p = 0.008$. Therefore, it is clear that participants spent more time planning in setting U2 than in U1. This further confirms that participants, in general, perceive the setting of the U2 environment as more challenging than U1.

8.5.5 Combining frequency and time of PDA usage

In this Section the relationship of total frequency $F_{pda\text{-}total}$, total time $T_{pda\text{-}total}$ and planning time $T_{plan\text{-}total}$ are investigated. Correlations between the three variables for both settings are given in Figure 8.19. It can be seen that $F_{pda\text{-}total}$ and $T_{pda\text{-}total}$ in both settings have a significant positive correlation in excess of 0.6. $T_{pda\text{-}total}$ also has a significant positive correlation with $T_{plan\text{-}total}$ > 0.6. However, $F_{pda\text{-}total}$ and $T_{plan\text{-}total}$ are not significantly correlated.

Urban Setting U1			$T_{pda\text{-}total}$	$T_{plan\text{-}total}$
Spearman's rho	$F_{pda\text{-}total}$	Correlation Coefficient	**0.620**	0.187
N = 27		Sig. (2-tailed)	0.001	0.349
	$T_{pda\text{-}total}$	Correlation Coefficient		**0.731**
		Sig. (2-tailed)		0.000

Urban Setting U2			$T_{pda\text{-}total}$	$T_{plan\text{-}total}$
Spearman's rho	$F_{pda\text{-}total}$	Correlation Coefficient	**0.653**	0.354
N = 27		Sig. (2-tailed)	0.000	0.070
	$T_{pda\text{-}total}$	Correlation Coefficient		**0.696**
		Sig. (2-tailed)		0.000

Table 8.19 Correlation matrices (significant correlations $p < 0.05$ in bold).

Ordinary least squares (OLS) regression was carried out between $F_{pda\text{-}total}$ and $T_{pda\text{-}total}$ for settings U1 and U2 with the results given in Figure 8.27 and Table 8.20. Both models are significant at $p < 0.05$. The regression model has a higher R^2 in U2, but this may be influenced by the outlier. In setting U1, the total frequency explains less of the variance in total time of PDA usage. This may relate to differences in the way PDA spatial information is used in setting U1 as compared with setting U2. This is further discussed in §8.7.

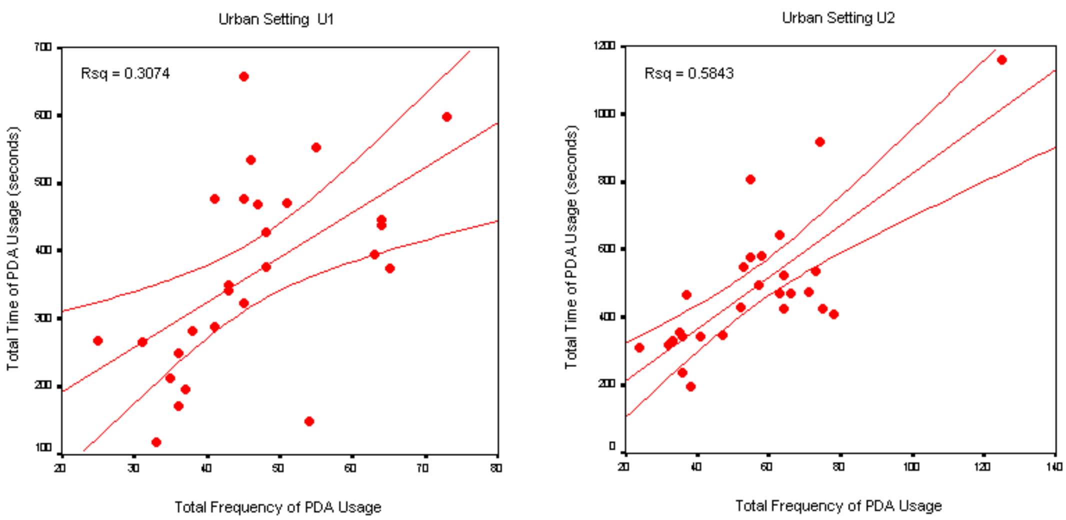


Figure 8.27 Regression models with 95% confidence intervals for $F_{pda\text{-}total}$ against $T_{pda\text{-}total}$ for settings U1 and U2

Urban Setting U1

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.554	0.307	0.280	118.940

Predictors: (Constant), Fpda-total
Dependent Variable: Tpda-total

Urban Setting U2

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.764	0.584	0.568	136.379

Predictors: (Constant), Fpda-total
Dependent Variable: Tpda-total

ANOVA (U1)

	Sum of Squares	df	Mean Square	F	Sig.
Regression	156989.394	1	156989.394	11.097	0.003
Residual	353669.273	25	14146.771		
Total	510658.667	26			

ANOVA (U2)

	Sum of Squares	df	Mean Square	F	Sig.
Regression	653613.578	1	653613.578	35.142	0.000
Residual	464981.162	25	18599.246		
Total	1118594.741	26			

Coefficients (U1)

	Coefficients	Std. Error	t	Sig.
(Constant)	59.576	95.049	0.627	0.536
Fpda-total	6.627	1.989	3.331	0.003

Coefficients (U2)

	Coefficients	Std. Error	t	Sig.
(Constant)	60.923	76.593	0.795	0.434
Fpda-total	7.653	1.291	5.928	0.000

Table 8.20: Regression statistics for *Fpda-total* and *Tpda-total* for settings U1 and U2

Similarly, regression has been carried out between *Tpda-total* and *Tplan-total* and for settings U1 and U2 with the results given in Figure 8.28 and Table 8.21. *Tpda-total* only consists the time spent in using the PDA. However, *Tplan-total* includes time spent using the PDA and time spent observing the environment and deciding the wayfinding strategy. *Tplan-total* is therefore not an inclusion set of *Tpda-total*. These have higher R^2 values as expected from the correlation matrix. Hence the planning time explains more variance in the total PDA time than the total frequency. Again, setting U2 has the stronger correlation. This also reflects differences in the planning of wayfinding between the two settings.

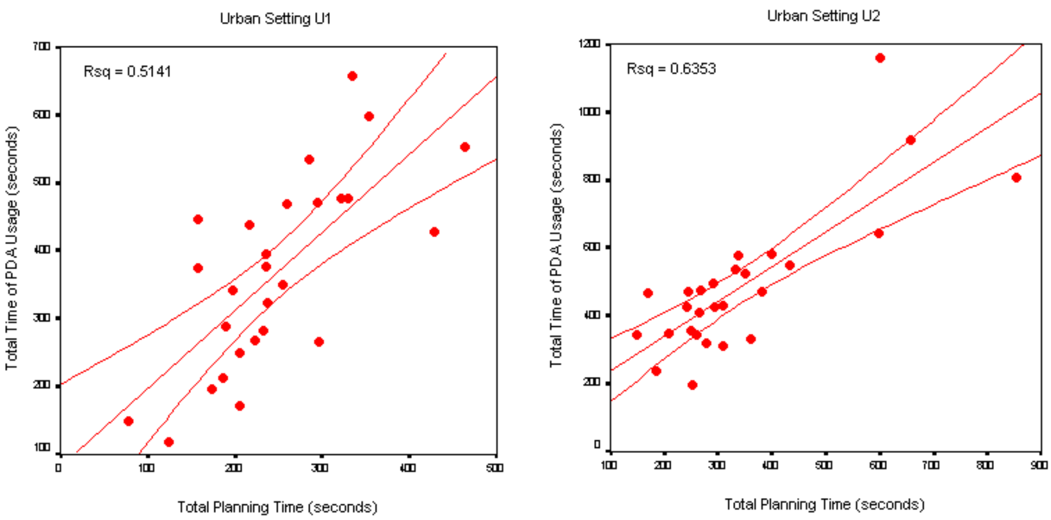


Figure 8.28 Regression models with 95% confidence intervals for *Tplan-total* and *Tpda-total* for settings U1 and U2

Urban Setting U1
Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.717	0.514	0.495	99.625

Predictors: (Constant), $F_{pda\text{-}total}$
Dependent Variable: $T_{plan\text{-}total}$

Urban Setting U2
Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.797	0.635	0.621	127.736

Predictors: (Constant), $T_{plan\text{-}total}$
Dependent Variable: $T_{pda\text{-}total}$

ANOVA (U1)

	Sum of Squares	df	Mean Square	F	Sig.
Regression	262528.943	1	262528.943	26.451	0.000
Residual	248129.723	25	9925.189		
Total	510658.667	26			

ANOVA (U2)

	Sum of Squares	df	Mean Square	F	Sig.
Regression	710680.616	1	710680.616	43.556	0.000
Residual	407914.125	25	16316.565		
Total	1118594.741	26			

Coefficients (U1)

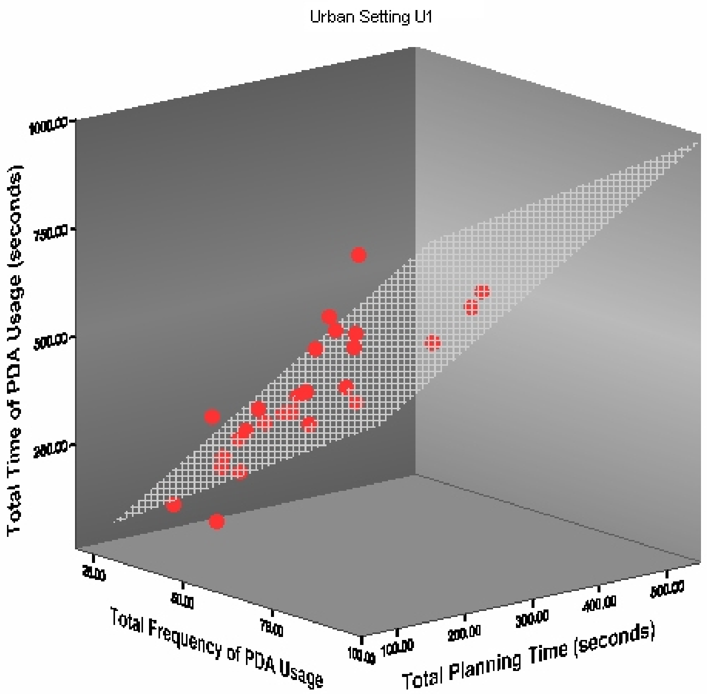
	Coefficients	Std. Error	t	Sig.
(Constant)	82.154	58.589	1.402	0.173
$T_{plan\text{-}total}$	1.151	0.224	5.143	0.000

Coefficients (U2)

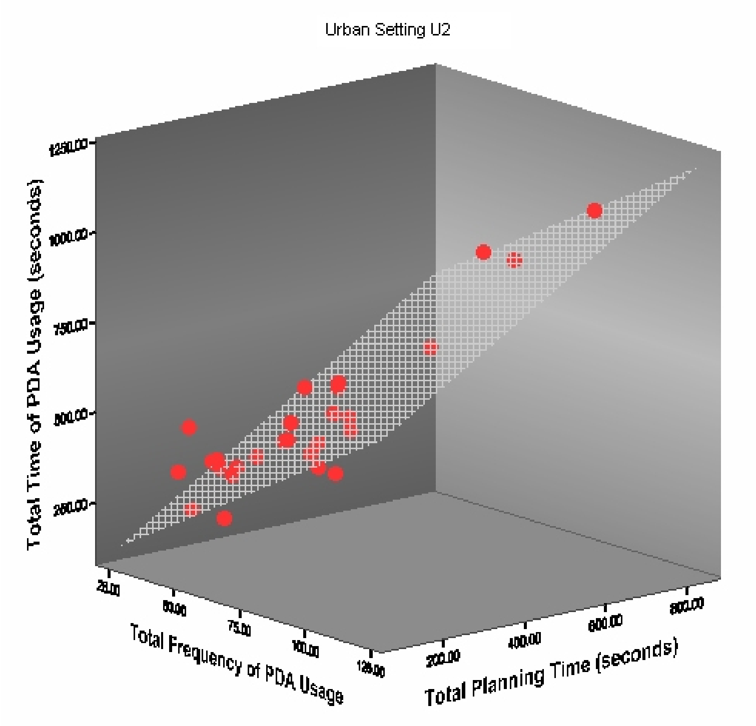
	Coefficients	Std. Error	t	Sig.
(Constant)	136.606	58.574	2.332	0.028
$T_{plan\text{-}total}$	1.021	0.155	6.600	0.000

Table 8.21 Regression statistics for $T_{plan\text{-}total}$ and $T_{pda\text{-}total}$ for settings U1 and U2

Given that $F_{pda\text{-}total}$ and $T_{plan\text{-}total}$ are not significantly correlated, with both correlating well with $T_{pda\text{-}total}$., it was considered possible to construct a multiple regression model for each setting between these two variables and the dependent variable $T_{pda\text{-}total}$. The results are given in Figure 8.29 (a) and (b) and Table 8.22. The results of the ANOVA given in Table 8.22 show that both multiple regression models are significant at $p < 0.001$. Again the R^2 is higher in setting U2 but with both in excess of 0.7. The amount of variance explained is high and therefore $F_{pda\text{-}total}$ and $T_{plan\text{-}total}$ can be taken as the main determinants of $T_{pda\text{-}total}$.



(a)



(b)

Figure 8.29 Multiple regression model (a) for setting U1; (b) for setting U2.

Urban Setting U1

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.854	0.729	0.706	75.939

Predictors: (Constant), Tplan-total, Fpda-total
Dependent Variable: Tpda-total

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	372256.510	2	186128.255	32.276	0.000
Residual	138402.157	24	5766.757		
Total	510658.667	26			

Coefficients

	Coefficients	Std. Error	t	Sig.
(Constant)	-152.448	69.907	-2.181	0.039
Fpda-total	5.590	1.281	4.362	0.000
Tplan-total	1.052	0.172	6.110	0.000

Urban Setting U2

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.923	0.852	0.839	83.099

Predictors: (Constant), Tplan-total, Fpda-total
Dependent Variable: Tpda-total

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	952864.896	2	476432.448	68.994	0.000
Residual	165729.845	24	6905.410		
Total	1118594.741	26			

Coefficients

	Coefficients	Std. Error	t	Sig.
(Constant)	-53.090	49.780	-1.066	0.297
Fpda-total	5.167	0.872	5.922	0.000
Tplan-total	0.735	0.112	6.583	0.000

Table 8.22 Statistics for multiple regression in Figure 8.29

Discussion: In Section 8.5, three main variables have been identified as key descriptors of PDA usage, namely the frequency of PDA information access, the task planning time and the time spent on PDA usage. In all cases, a significant difference was found between settings U1 and U2, with U2 having higher median values. Thus setting U2 appears to have been more challenging for participants. Furthermore, this analysis supports the suggestion that spatial layout and environment along the route do have an influence on frequency of PDA access and usage. This is further supported by the patterns of spatial distribution of PDA usage given in the intensity maps (Figures 8.19 and 8.20). Furthermore, there is evidence that particular routes present participants with specific challenges as reflected in the heightened PDA information access and time spent using the PDA. This will be further explored as part of the case studies in §8.7.

Whilst the preceding analysis has focused on aggregate PDA information usage, as discussed in §8.5.2 and §8.5.3, it is nevertheless important to study the variables on frequency and time spent using the constituent types of information, such as overview maps, detailed maps and route information. This will be further addressed in the next Section.

The sequence in which participants undertook experiments in urban setting U1 and U2 has been further analysed for any effects on PDA information usage that such sequencing might produce. For example, there might be a learning effect which could change the way in which the PDA was being consulted for information (frequency, time). If this was found to be the case, it would be difficult to combine all participants in a single analysis of each setting. The significance tests have shown that there are no consistent differences between participants undertaking the various tasks in a different sequence and therefore all the results for a setting can be studied together. Moreover, this is a positive sign as the data collected reflects participants' unaltered abilities applied to both settings.

From the regression models (Figure 8.29) it can been seen that frequency of PDA access and planning time, when specified as uncorrelated independent variables, have a strong relationship with total PDA usage time. There is, however, a difference between setting U1 and U2 with a higher R^2 goodness of fit in setting U2.

8.6 Classification of individual PDA spatial information usage

The usage of spatial information through consulting the PDA can be quantified using two main categories of variables: the frequency of information access and the time spent for consulting and studying the information. As discussed in the previous Section, there are different types of information which can be accessed and used via the PDA during the wayfinding tasks. To recap, these variables on PDA spatial information transaction are:

- Frequency for total (any) PDA information access – $F_{pda\text{-}total}$
- Frequency for all types of map information access – $F_{pda\text{-}map}$
- Frequency for overview map information access – $F_{pda\text{-}o\_map}$
- Frequency for detailed map information access – $F_{pda\text{-}d\_map}$
- Frequency for route information access – $F_{pda\text{-}route}$
- Time spent on total PDA information usage – $T_{pda\text{-}total}$
- Time spent on all types of map information usage – $T_{pda\text{-}map}$
- Time spent on overview map information usage – $T_{pda\text{-}o\_map}$
- Time spent on detailed map information usage – $T_{pda\text{-}d\_map}$
- Time spent on route information usage – $T_{pda\text{-}route}$

The values of frequency of PDA information access and time spent for PDA information usage include the time spent on accessing information during task planning. Therefore, planning time is not considered separately here. In this Section, analysis of the variables on frequency of access and time spent for each type of information (overview map, detailed map and route information) will be carried out. Patterns of individual preferences for types of information will be derived from this analysis.

For eight out of the ten variables listed above, factor analysis has been used to explore whether the PDA spatial information usage variables can reasonably be reduced to a smaller number of dimensions. The motivation for so doing was to use such dimensions in order to classify individual participants according to their PDA spatial information usage. The variables $F_{pda\text{-}total}$ and $T_{pda\text{-}total}$ were not included in the factor analysis, because the value of these variables sum from the others. However, variables $F_{pda\text{-}map}$ and $T_{pda\text{-}map}$ have been included because, as will become evident from the factor analysis, these two variables do inform patterns of preference over and above what their constituent parts are able to show on their own. Although these may result in an ill-conditioned correlation matrix (Longley, 1967; Mather, 1976), the software (Statistica) handles this by reducing the maximum number of factors that can be extracted. In this analysis, however, the number of factors taken forward is in any case much smaller than the total extracted and the exploratory analysis should be safe.

For the factor analysis, the Kaiser criterion and scree test have been used to select the number of factors which should be retained. Following the Kaiser criterion, the only factors that should normally be retained are those with eigenvalues greater than 1. In other words, only the factors extracting at least as much as the equivalent of one original variable are retained. Therefore, the three factors given in Table 8.23 can be retained because their eigenvalues are all greater than 1. From the scree plot (Figure 8.30), the factors to be retained are normally those above the inflection where the eignevalues level off (the scree). From these two criteria, three factors have been retained. Additionally, the cumulative percentage values of explained variance given in Table 8.23 show that the variance explained by these three factors is 93.948%.

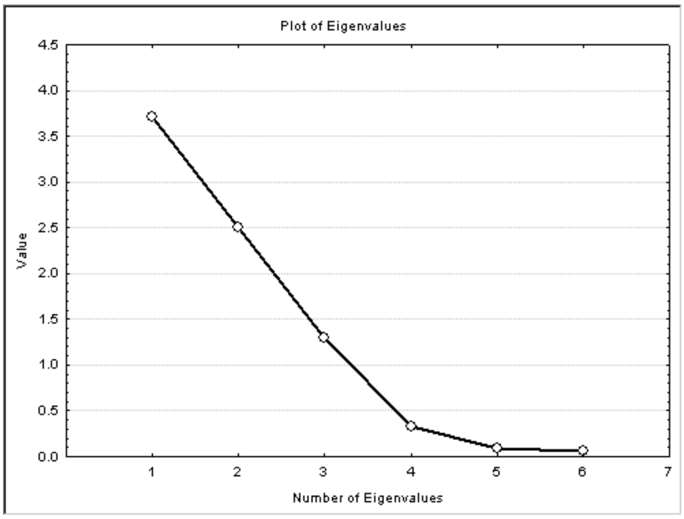


Figure 8.30 Scree plot of Eigenvalues

Eigenvalues
Extraction: Principal components

	Eigenvalue	% Total variance	Cumulative Eigenvalue	Cumulative %
1	3.709	46.362	3.709	46.362
2	2.504	31.297	6.213	77.659
3	1.303	16.289	7.516	93.948

Table 8.23 The Eigenvalues and the percentages of variance explained.

Table 8.24 gives the factor loadings after rotation using Varimax normalisation. Taking the usually accepted cut-off value of > 0.7, it can be seen that the variables with high loadings (>0.7) are mutually exclusive to the three factors. It is therefore straightforward to interpret these factors as follows:

- Factor 1 is marked by high loadings on variables $T_{pda\text{-}o\_map}$, $F_{pda\text{-}map}$ and $F_{pda\text{-}o\_map}$. This indicates that Factor 1 is characterised by the usage of the overview map through the PDA both in frequency of access ($F_{pda\text{-}o\_map}$) and time spent on studying such information through the PDA ($T_{pda\text{-}o\_map}$). Furthermore, there is a high loading on the total frequency of PDA map information access ($F_{pda\text{-}map}$). This may reflect the relationship between overview map usage and the total frequency of map information access whereby the usage of the overview map is characterised by more clicking of the PDA to find landmarks and street names.

- Factor 2 is marked by high loadings on variables $T_{pda\text{-}map}$, $T_{pda\text{-}d\_map}$, $F_{pda\text{-}d\_map}$. Thus Factor 2 reveals the usage of the detailed map via the PDA both in time spent studying such information, $T_{pda\text{-}d\_map}$, and the frequency of access, $F_{pda\text{-}d\_map}$. Additionally, there is a high loading on the variable for total time spent on PDA map information usage ($T_{pda\text{-}map}$). This could indicate that detailed map usage is linked to the total time spent for PDA map information usage ($T_{pda\text{-}map}$), but not on the frequency for total PDA map information access ($F_{pda\text{-}map}$). This then differs from Factor 1.
- Factor 3 is marked by high loadings on variables $T_{pad\text{-}route}$, and $F_{pda\text{-}route}$. This factor thus evidently reflects the usage of PDA route information in both frequency of access and time spent in PDA usage for such information.

Factor Loadings (Varimax normalized)
Extraction: Principle Components
(Marked loadings are >.7000)

	Factor 1	Factor 2	Factor 3
Tpda-map	-0.6471	**0.7113**	0.0966
Tpda-o_map	**-0.9320**	-0.0377	0.1721
Tpda-d_map	0.0261	**0.9861**	-0.0354
Tpda-route	0.1092	0.0676	**-0.9713**
Fpda-map	**-0.8254**	0.4331	0.1868
Fpda-o_map	**-0.9193**	-0.2293	0.2083
Fpda-d_map	0.0525	**0.9751**	-0.0122
Fpda-route	0.2999	-0.0765	**-0.9240**
Explained Variance	2.9189	2.6810	1.9160
Propotin of Total	0.3649	0.3351	0.2395

Table 8.24 Factor loadings on the raw variables.

From the factor analysis results and the discussion above, the three factors extracted from the eight PDA spatial information usage variables, can be regarded as describing three different aspects of the PDA spatial information usage. They are referred as three dimensions of PDA spatial information usage here, denoted as PDA-D1, PDA-D2 and PDA-D3. Dimension PDA-D1 reflects overview map usage with some additional measure of frequency of total PDA map information access, including variables $T_{pda\text{-}o\_map}$, $F_{pda\text{-}o\_map}$ and $F_{pda\text{-}map}$. Dimension PDA-D2 reflects detailed map usage with additional loading on time spent on studying total PDA map information, including variables $T_{pda\text{-}map}$, $T_{pda\text{-}d\_map}$ and $F_{pda\text{-}d\_map}$. The third dimension, PDA-D3, reflects route information usage, including variables $T_{pda\text{-}route}$ and $F_{pda\text{-}route}$. Having thus arrived at a classification of the variables, it is now possible to take this forward to a classification of PDA usage by individuals.

Using the variables in each of the three dimensions, the value of each variable was normalised to [0,1] using a min/max transformation. Three indices were then created by combining the relevant variables giving equal weighting. These three indices were used to derive a classification tree using Ward's method. Four groups have been identified, marked as 1 to 4 in Figure 8. 31. These four groups are denoted as IN-G1 through IN-G4 and are used to represent individual preferences in PDA spatial information usage. The IN-G1 and IN-G2 groups are clearly separated from the rest as shown by the linkage distance in the tree diagram (Figure 8.31); however, it is arguable that IN-G3 and IN-G4 should be combined into a single group. Therefore, further analysis was carried out both in plotting these groups against the three PDA dimensions and in statistical tests.

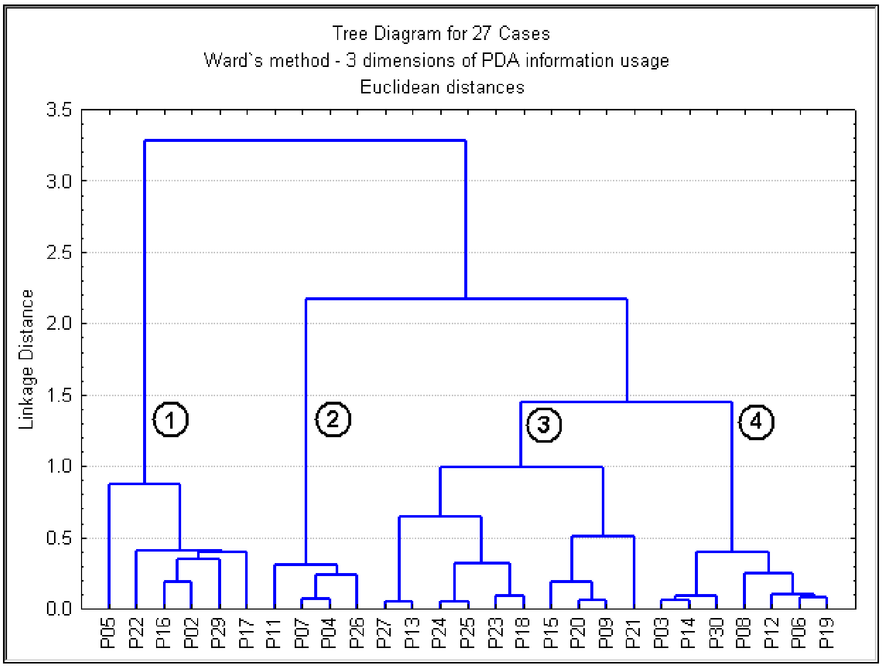
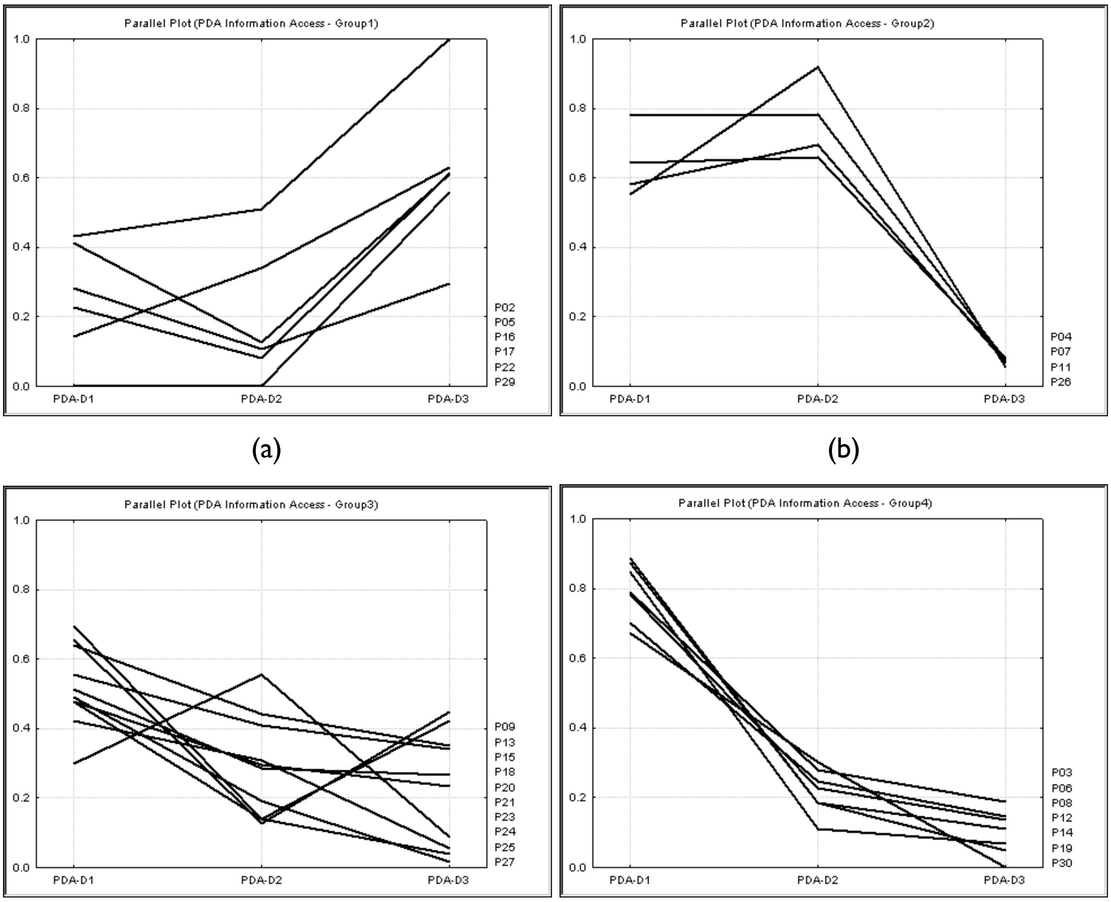


Figure 8.31 Classification tree of individual PDA information usage.

The value of the three indices, representing the three PDA usage dimensions, for all participants in the four PDA spatial information usage groups (IN-G1 to IN-G4) are illustrated using parallel plots. The four groups are shown in Figure 8.32(a), (b), (c) and (d) respectively. As illustrated in these parallel plots, the participants in IN-G1 have much higher scores in the dimension PDA-D3 (PDA route information usage) compared to the other two dimensions within the group. In addition, their scores in the dimension PDA-D3 are also higher than any of the other usage groups. Thus the Group IN-G1 can be concluded as having a pattern of preferring route information to other types of information for their wayfinding tasks. The participants in both groups IN-G2 and IN-G4 have low scores in the dimension PDA-D3. However, participants in IN-G4 Group have much higher scores in the dimension PDA-D1 (overview map information) with much lower scores in the dimension PDA-D2 (detailed map information). The scores in PDA-D1 are also much higher than those of any other usage group. On the other hand, the participants in IN-G2 have high scores on both dimensions PDA-D1 and PDA-D2. These might reflect the ways in which members of Group IN-G2 use both types of map for their wayfinding tasks, or use the overview map to access the detailed maps of particular areas. Finally, the participants in the IN-G3 Group do have slightly higher scores in the dimension PDA-D1 and slightly lower scores in the dimension PDA-D3. Thus, the participant pattern of using PDA spatial information in this group does not seem to show any particular preference for any one type of spatial information. This also confirms that the classification with IN-G3 and IN-G4 as two separate groups is more acceptable than any which might combine them into a single group. Moreover, the distinctive (Figure 8.32(d)) pattern of preferences amongst the members of Group IN-G4 might be difficult to discern in any such combined group.



(a) (b) (c) (d)

Figure 8.32 Parallel plots for four PDA spatial information groups:
(a) IN-G1; (b) IN-G2; (c) IN-G3; (d) IN-G4.

Kruskal-Wallis tests were carried out for the four PDA spatial information usage groups. These four groups are all significantly different at $p < 0.05$ with regard to the three underlying variables (Table 8.25), reinforcing the conclusion that the classification of individual PDA usage into four groups is sound.

Dimension	*Kruskal-Wallis test result*
PDA-D1	H (3, N= 27) =20.698 p =.0001
PDA-D2	H (3, N= 27) =11.787 p =.0082
PDA-D3	H (3, N= 27) =13.656 p =.0034

Table 8.25 Statistical tests for the four groups IN-G1 to IN-G4

The four PDA spatial information usage groups (abbreviated here as PDA information usage, or just PDA usage) were also cross tabulated with participant self-assessments of spatial abilities (SA) using the groups SA-G1 to SA-G3 (Table 8.26). These SA groups were derived from the analysis of self-assessed spatial ability scores, which were discussed in §8.2. The figures in Table 8.26 show the numbers of the participants falling throughout the cross classification. At first glance, there appears to be no strong match between these two types of groups. However, the general tendency shows that the majority of the participants in SA-G3 (with higher self-assessed spatial ability scores) have preferences for map-oriented spatial information, whilst participants in SA-G2 use a range of spatial information. Interestingly, nearly half of the participants in SA-G1 (with low self-assessed spatial ability scores) have preferences for route information, while the remainder prefer the mixture of route and map information form the overview maps. The numbers of participants in the four PDA spatial information usage groups have also been compared with the numbers of participants in the three groups with tendencies for route, landmark and map thinking (TK-Groups) TK-G1 to TK -G3 (Table 8.27). These TK groups were derived from the analysis of self-assessed spatial ability scores, (§8.2.2). Again, although there is no simple match between these two groups, the numbers of the participants in TK-G1 (with a self-assessed tendency for map and landmark thinking) all fall into the PDA usage groups IN-G2 to IN-G4, which have strong preferences on the map information usage. However, the participants in TK-G2 (with a self-assessed tendency for route and landmark thinking) are split between the Group IN-G1 (route information usage) and the Group IN-G3 (mixed spatial information usage). Because of the small numbers falling into each category in the crosstables, no statistical tests have been carried out.

	PDA-Usage			
SA-Group	IN-G1 (route)	IN-G2 (detailed map)	IN-G3 (mixed)	IN-G4 (overview map)
SA-G1 (low score)	3	0	1	3
SA-G2 (intermediate score)	1	1	5	
SA-G3 (high score)	2	3	4	4

Table 8.26 Crosstabulation of observed PDA usage and self assessment of spatial ability (SA).

	PDA-Usage			
TK-Group	IN-G1 (route)	IN-G2 (detailed map)	IN-G3 (mixed)	IN-G4 (overview map)
TK-G1 (map + landmark)		3	2	6
TK-G2 (route + landmark)	4	1	5	1
TK-G3 (all)	2	0	3	0

Table 8.27 Crosstabulation of observed PDA usage and tendency for route, landmark and map thinking (TK).

Discussion: In this Section, a range of variables on the usage of spatial information by consulting the PDA have been classified into three dimensions using factor analysis. These three dimensions, PDA-D1 to PDA-D3, can be identified relating to route information usage, overview map usage and detailed map usage. The four resultant PDA spatial information usage groups, IN-G1 to IN-G4, have been established by means of a classification tree based on the three PDA dimensions (Figure 8.31). From the parallel plots (Figure 8.32), the different patterns between these four groups show that there are clear preferences in types of spatial information used by individuals during their wayfinding tasks. The participants in Group IN-G1 have a preference for route information during wayfinding tasks. Members of the Group IN-G4 have strong preference for overview maps of the area over other types of information. This group also uses (IN-G4) overview maps in association with landmark information. The access of landmark information by clicking on the overview map may be manifest in the frequency of total PDA map information ($F_{pda\text{-}map}$) scores, which is one of the underlying variables in PDA-D1 (overview map usage). The participants in Group IN-G2 have a preference for detailed maps over route information. The preference for overview maps is also evident amongst the members of this group. This could result from the ways in which detailed map information is accessed through the initial display of an overview map. However, the participants in this Group (IN-G2) tend to have their main preference as using detailed maps. The variable $T_{pda\text{-}map}$, which is one of the underlying variables in PDA-D2 (detailed map usage), reflects the time spent on studying PDA map information. In other words, high scores in PDA-D2 could also be indicative of greater time spent studying detailed PDA maps. Furthermore, the figures shown in the crosstable (Table 8.26), suggest discernible relations between self-assignments of spatial ability groups (SA groups) and observed PDA spatial information usage (IN groups). Similarly, trends can be identified between assignments to the four IN groups and the three TK groups (tendency for route, landmark and map thinking). The self-assessed SA groups and TK groups, therefore, may provide a useful means of understanding preferences for spatial information usage. However, there is not a clear relationship. The four individual PDA groups, established through the three PDA dimensions from measured activities, do have a clear pattern in preferences in PDA spatial information usage.

8.7 Case studies

In the preceding Sections, a range of variables has been elicited from the empirical data to describe and measure wayfinding behaviour and PDA spatial information usage. Analyses have been carried out to investigate these variables in relation to the two different urban settings and the three different self-assessed spatial ability groups. Furthermore, a classification has been established based on the individual PDA spatial information usage. In §8.7.1, group level case studies of three self-assessed spatial ability (SA) groups and the four PDA information usage (IN) groups are presented in respect of spatial layout and spatial information usage. In §8.7.2, individual level case studies are examined, largely qualitatively, in respect of spatial information usage, wayfinding strategies and spatial knowledge recall. These cases concerns eight individuals picked from different SA and IN groups.

8.7.1 Case studies: group level

The first group level study is of the three spatial ability groups (SA-G1, SA-G2 and SA-G3) which have been derived from the analysis of self-assessed questionnaire responses (see §8.2.2). To recap, SA-G1 is low self-assessed spatial ability group, SA-G2 suggest intermediate self-assessed spatial ability and SA-G3 suggest high self-assessed spatial ability. The intensities of the wayfinding position track points were mapped for the participants in these three groups for both settings U1 and U2, as shown in Figures 8.33 to 8.35. These intensity maps were created using kernel density estimation with 1 metre cell size and 10 metre bandwidth. Although the method used is the same as the one used to illustrate the spatial distribution for all participant tracks (Figure 8.10 and Figure 8.11), it is also possible to map similar distributions for the different spatial ability groups. In these maps, higher intensity locations show where participants move less or dwell for prolonged periods. Low intensities are where participants spend less time. In a similar way to the analysis carried out in previous Sections on the variables which describe wayfinding behaviour and PDA information usage, the patterns shown in these intensity maps can be used to identify differences in wayfinding behaviour between the three groups.

Before investigating the intensity maps of wayfinding tracks, the differences between the three spatial ability groups were tested in respect of two variables: distance travelled ($D_{travelled}$) and time taken for completion ($T_{completion}$). These two variables were discussed in §8.4 as two factors describing wayfinding performance. The results from Kruskal-Wallis tests show that there is a significant difference ($H(2,27)=10.300$, $p=0.006$) between the three groups for setting U1 with respect to the distance travelled: however, there is no significant difference between them with respect to time taken for completion. From the distribution of variable $D_{travelled}$ shown in Figure 8.33, the participants in SA-G2 and SA-G3 have a high median value of $D_{travelled}$, whilst the participants in SA-G1 have low median values of $D_{travelled}$. This might reflect that the participants from SA-G2 and SA-G3 were able to exercise more diversity in their route choices in setting U1. Nevertheless, they did not spend more time in completing the wayfinding tasks. This is confirmed in the discussion below. There is no significant difference between the three SA groups in settings U2 with respect of $D_{travelled}$ and $T_{completion}$.

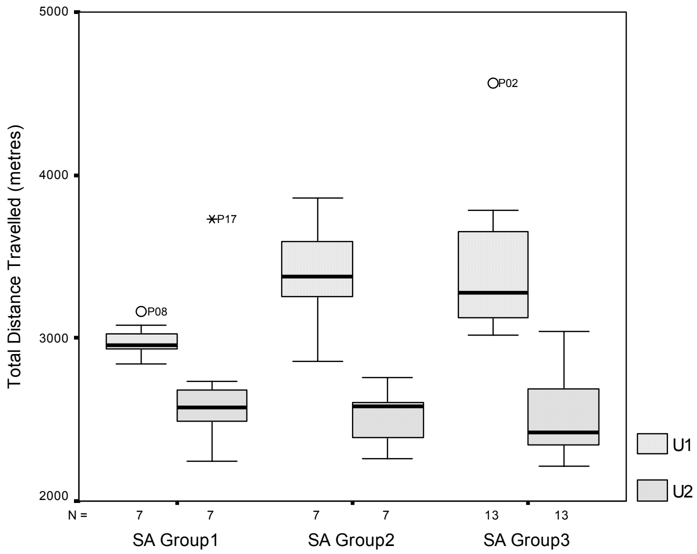
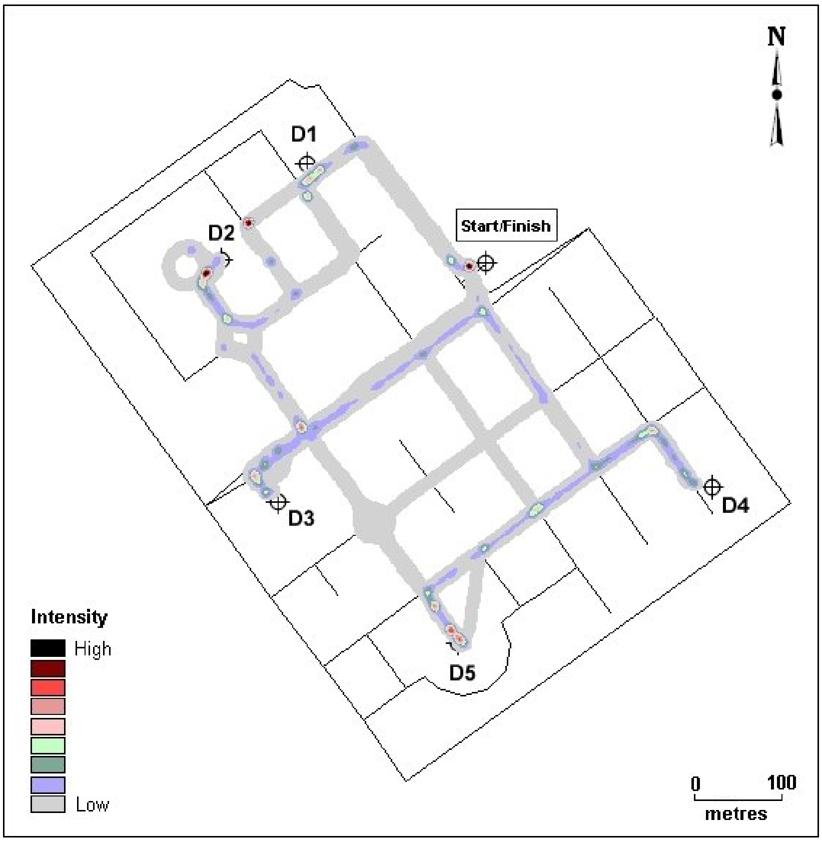
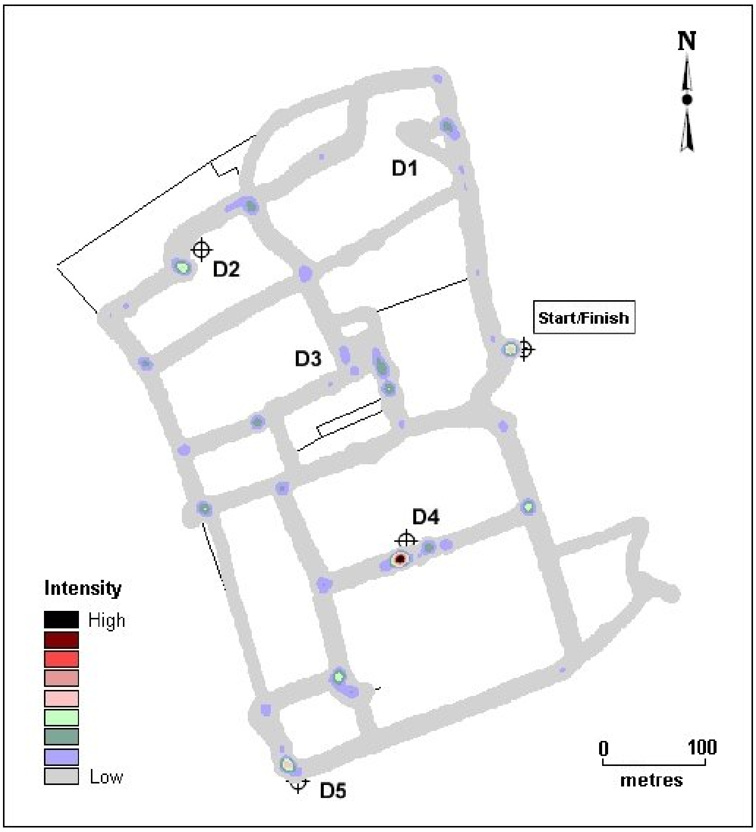


Figure 8.33 Boxplot of variable $D_{travelled}$ for three SA groups in settings U1 and U2

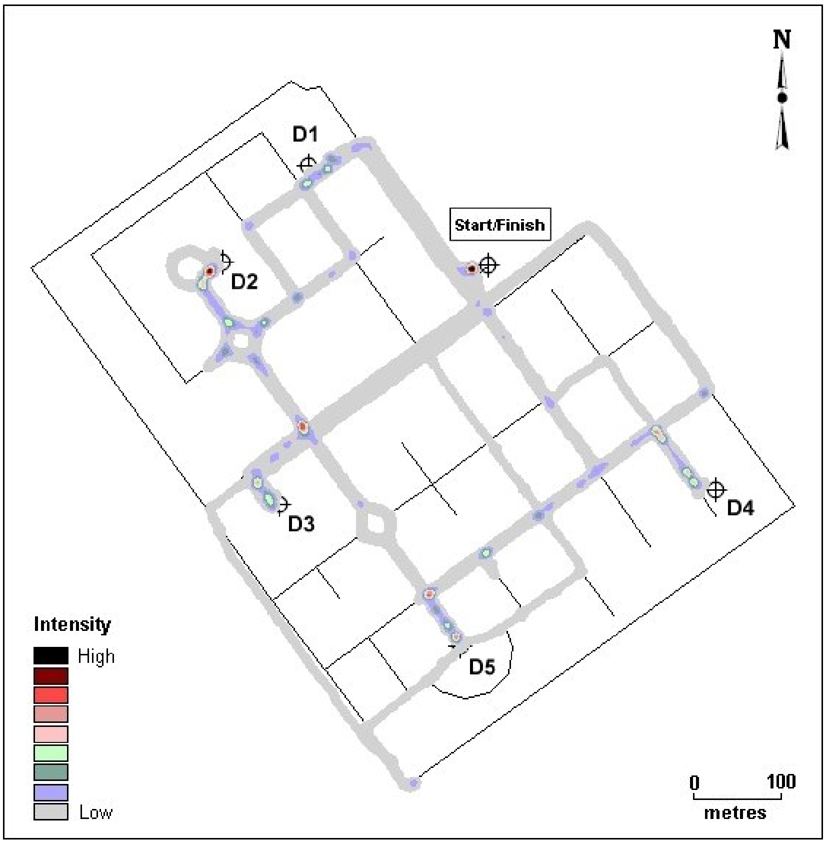


(a)

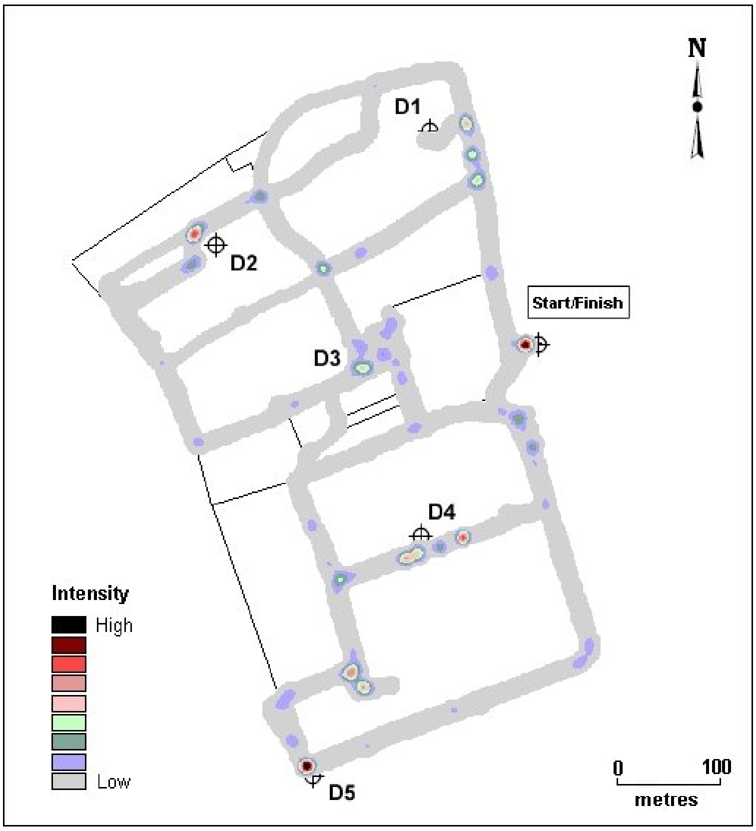


(b)

Figure 8.34 Intensity maps for self-assessed spatial ability Group SA-G1 (low score): (a) setting U1; (b) setting U2.

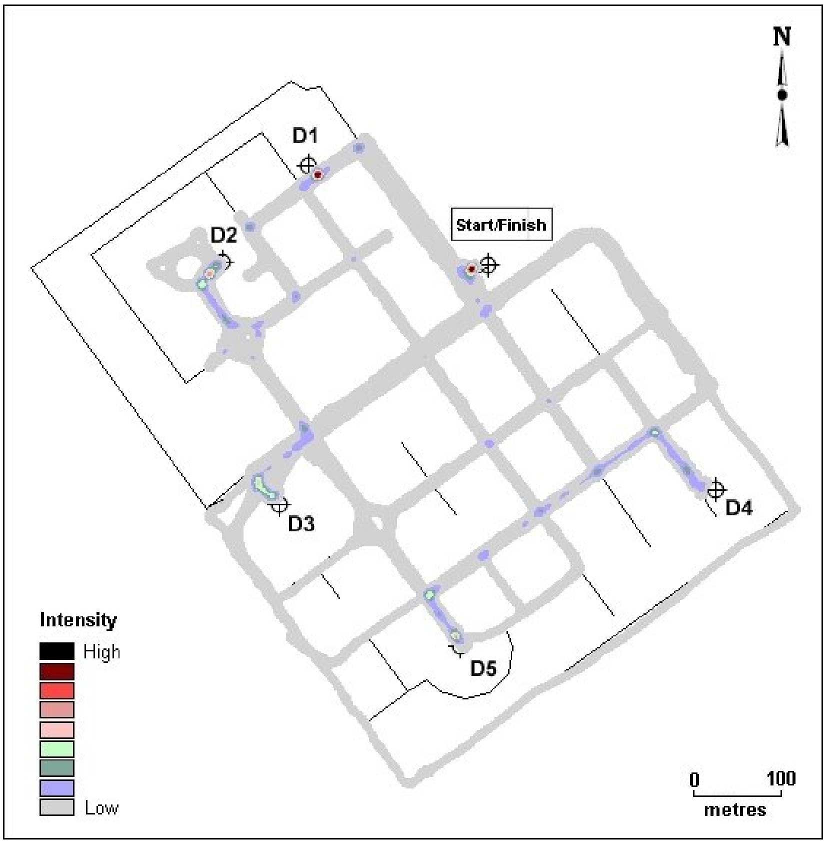


(a)

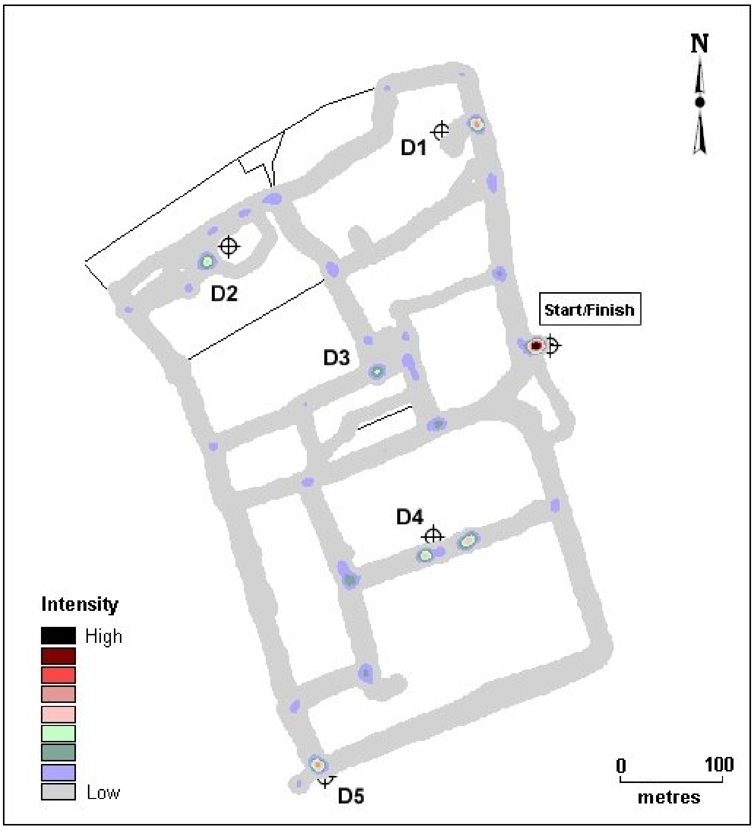


(b)

Figure 8.35 Intensity maps for self-assessed spatial ability Group SA-G2 (medium score): (a) setting U1; (b) setting U2.



(a)



(b)

Figure 8.36 Intensity maps for self-assessed spatial ability Group SA-3 (high score): (a) setting U1; (b) setting U2.

The patterns in the intensity maps for the three groups reveal a number of differences between them. The lowest intensity areas represent locations through which participants pass without stopping. All intensities above this indicate locations where participants stopped or lingered either to consult the PDA or to observe the environment. Thus apart from showing which route options were used by participants, any intensity above the lowest is of interest. To begin with, there is greater diversity in the number of different routes chosen (out of the total available) by the participants in SA-G3 for their wayfinding (Figure 8.36 (a) and (b)) compared with the other two groups. When observing this diversity across the two different settings, it occurs in both though such diversity is demonstrated more obviously in setting U1 than in setting U2. Next, there is a similarity in the locations with higher intensity amongst the three groups for both settings. An example is the higher intensity locations at the start points for each wayfinding task. A location with higher intensity (above lowest intensity) will be referred to as a 'hotspot', although hotspots themselves can have different intensities. This phenomenon shows that participants from all three SA groups spent time for planning their wayfinding at the beginning of the tasks. This is consistent with the analysis of the task planning time (§8.5.4). However, an important difference in the patterns of hotspots can be observed between the three groups, that is the different distribution of such hotspots. Shown in Figure 8.34 (a), for the participants in SA-G1, only a number of the hotspots are located at the start points of the wayfinding tasks (e.g. at D2 and D5) whilst others are located at road junctions. For the participants in SA-G2, shown in Figure 8.35 (a), the hotspots are located both at start points and some of road junctions. But for SA-G3 participants (Figure 8.36 (a)), there is a clear concentration of such hotspots at the starting points of wayfinding tasks, particularly in the early part of the entire journey. This is even more obvious in setting U2 (Figure 8.36(b)), where the start point of the whole journey is the highest intensity location throughout the entire wayfinding routes.

Comparing the two different settings, the participants in SA-G1 Group have more evenly distributed hotspots at start points and road junctions in setting U2 (Figure 8.34(b)). The higher intensity hotspot at D4 might reflect that the participants perceived some challenge for the coming wayfinding task from D4 to D5 (this location will be analysed in detail in §8.7.2). This route in setting U2 also posed a challenge to the participants in SA-G2 (see the hotspots along the route between D4 and D5 in Figure 8.35 (b)). In setting U2, the distribution of hotspots for the participants in SA-G2 are mainly at the starting points of the various wayfinding tasks and some locations where participants felt the need for more information. The route D4 to D5 in setting U2, which appears to be a challenge to the participants in SA-G1 and SA-G2, does not cause such high intensity hotspot for the participants in SA-G3 (Figure 8.36(b)).

The three spatial ability groups are further investigated in terms of the frequency of being lost or confused. These frequency data were elicited from the individual wayfinding track position data and observation data based on the number of time participants were lost and/or confused. The track position data can show behaviour consistent with being lost (such as taking an obvious wrong turning, overshoot and turning back) or confused (such as dwelling at points of choice not knowing where to go). The observation data also recorded such incidences either from the investigator direct observation or from participants' own admissions. As shown in the Figure 8.37, the frequency of being lost or confused for the participants in SA-G1 is higher in setting U2 than in setting U1. The participants in SA-G2 and SA-G3 performed more consistently in both settings in terms of the number of times that they were lost or confused. In other words, the difference between urban settings has greater effect upon participant wayfinding performance in SA-G1 than for participants in the other groups. Kruskal-Wallis tests show that there is a significant difference between the three groups in setting U1 in respect of the frequency of being lost or confused, $H(2,27) = 9.006$ $p = 0.011$, but not in setting U2, $H(2,27) = 1.300$ $p = 0.522$.

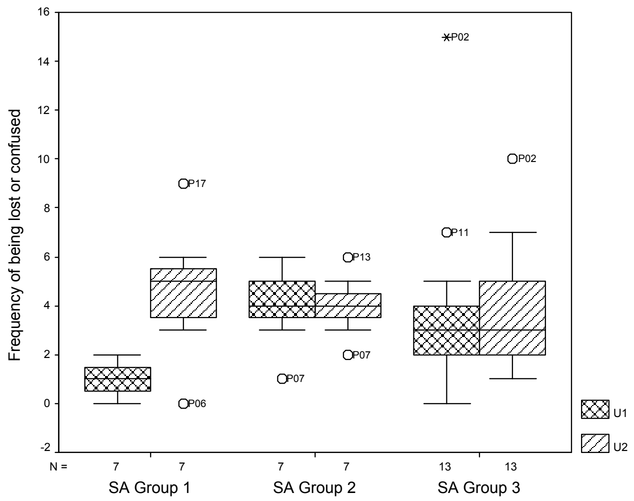


Fig 8.37 Frequency of being lost or confused for three SA groups in settings U1 and U2

The second case study here is of the four PDA spatial information usage groups, which were classified based on the three indices derived from a range of PDA information usage variables (see §8.6). To recap, these four groups are: Group IN-G1 with route information oriented usage; Group IN-G2 with map oriented usage with clear preferences for detailed maps; Group IN-G3 with mix mode of information usage; and Group IN-G4 with map oriented usage and clear preferences for overview maps.

To begin with, statistically, there is no significant difference between these four groups in terms of distance travelled or time taken for completing wayfinding tasks. However, the time used for task planning shows a significant difference, at $p < 0.05$ level, between the four groups in setting U1, but not in setting U2: setting U1 $H(3, N=27) = 10.688$ $p = 0.014$; setting U2 $H(3, N=27) = 7.584$ $p = 0.055$. As shown in Figure 8.38, the participants in information usage Group IN-G2 have highest values for total planning time ($T_{plan-total}$) compared with the other groups. When in setting U2, there appears to be a greater range in $T_{plan-total}$ amongst the participants in this group. This appears to have been caused by the more irregular layout of setting U2 giving participants additional challenges in planning their routes, predominantly using detailed maps. Furthermore, the influence of the setting has a much less marked effect on $T_{plan-total}$ for groups IN-G1 and IN-G3, which are the route information usage and mix mode information usage groups. The settings do appear to have an influence on the median value of $T_{plan-total}$ for the participants in IN-G4 which is the overview map information usage group, setting U1 requiring this group to spend less time for planning.

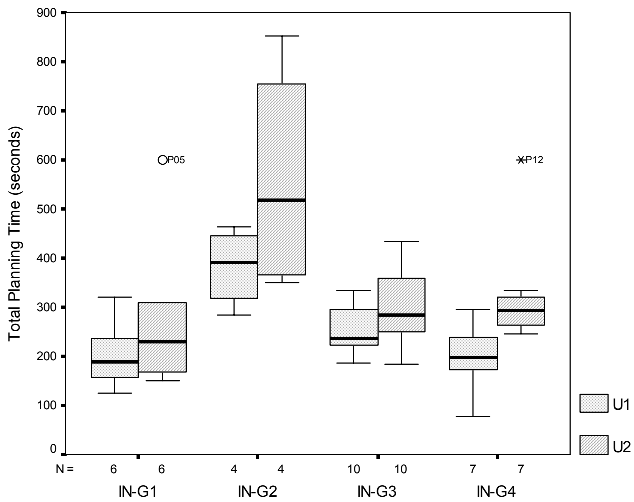
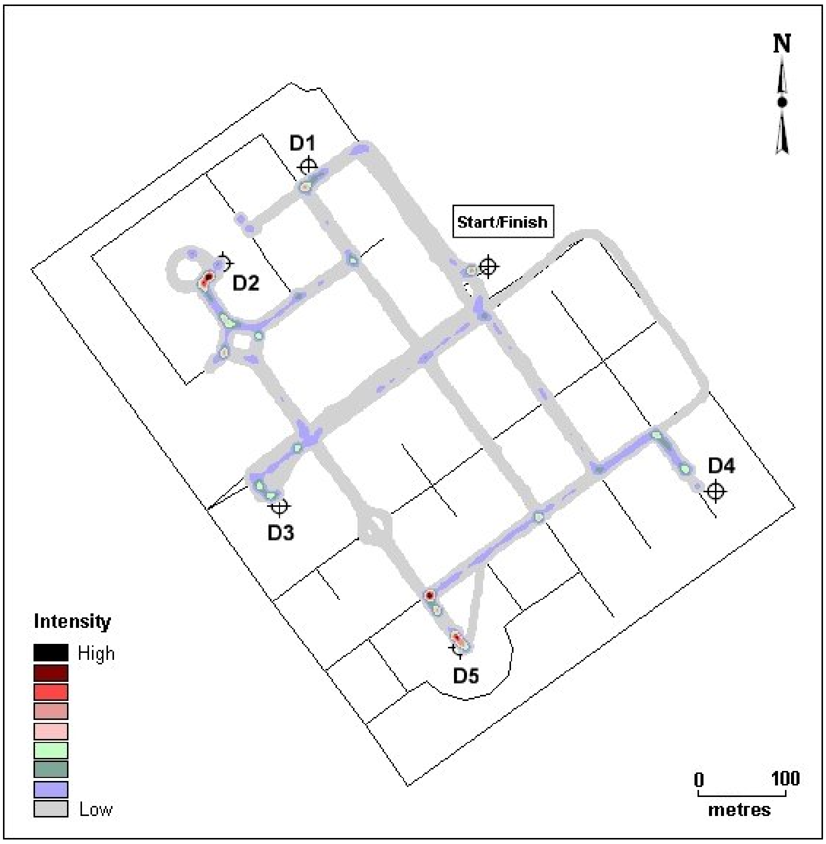
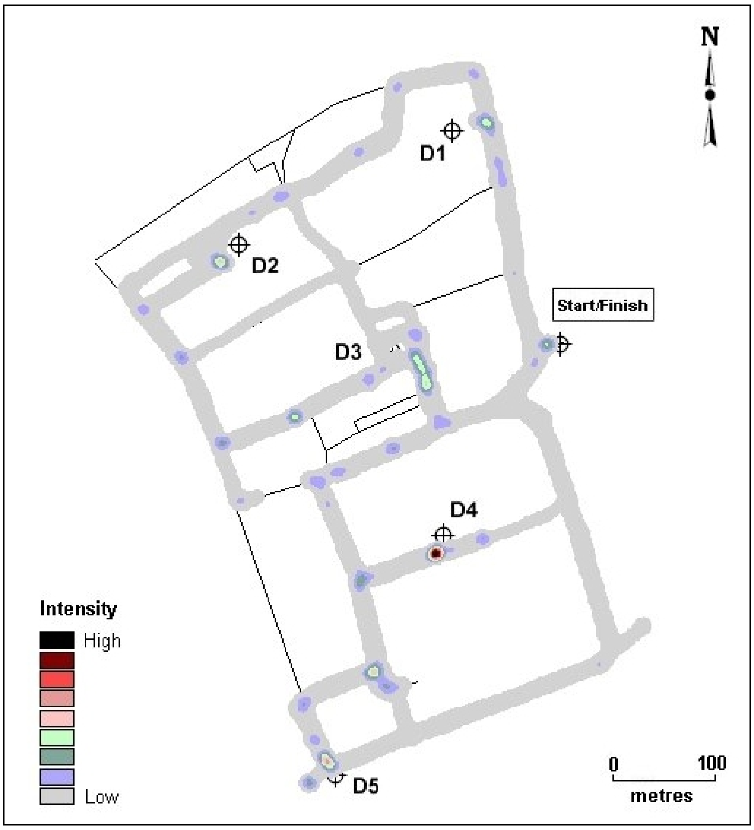


Figure 8.38 Boxplots of planning time ($T_{plan-total}$) for the four IN groups in settings U1 and U2

Eight intensity maps of the track position points recorded during wayfinding (Figure 8.39 to Figure 8.42) were also created for these four groups in both settings, in a similar way as described in the first case study above. The patterns shown in these intensity maps are discussed below to explore aspects of wayfinding behaviour of the four PDA information usage groups.



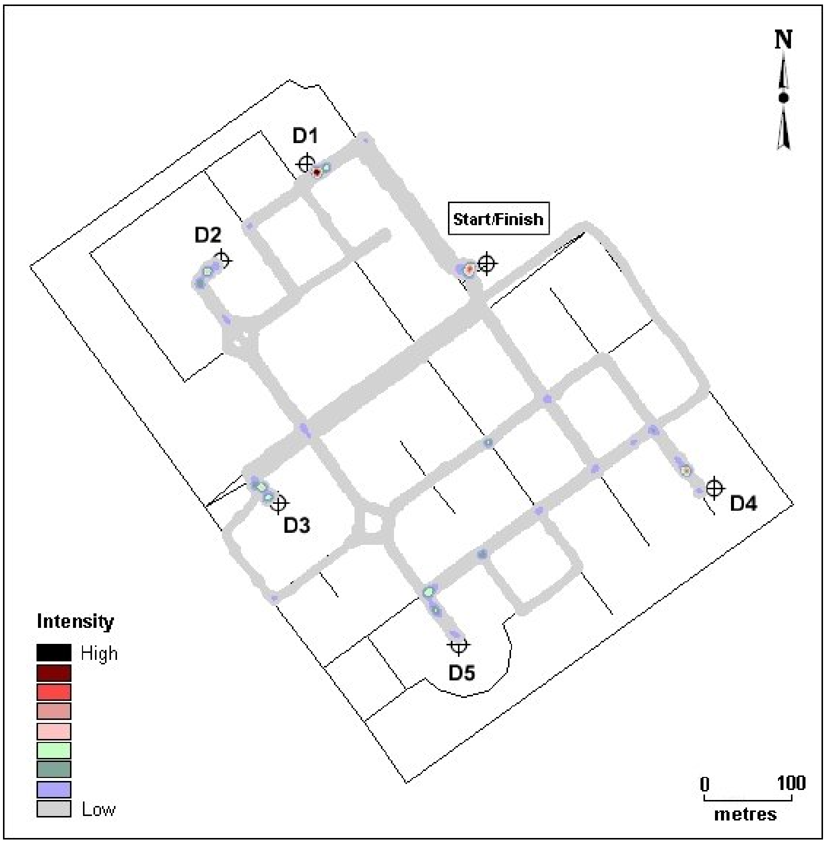
(a)



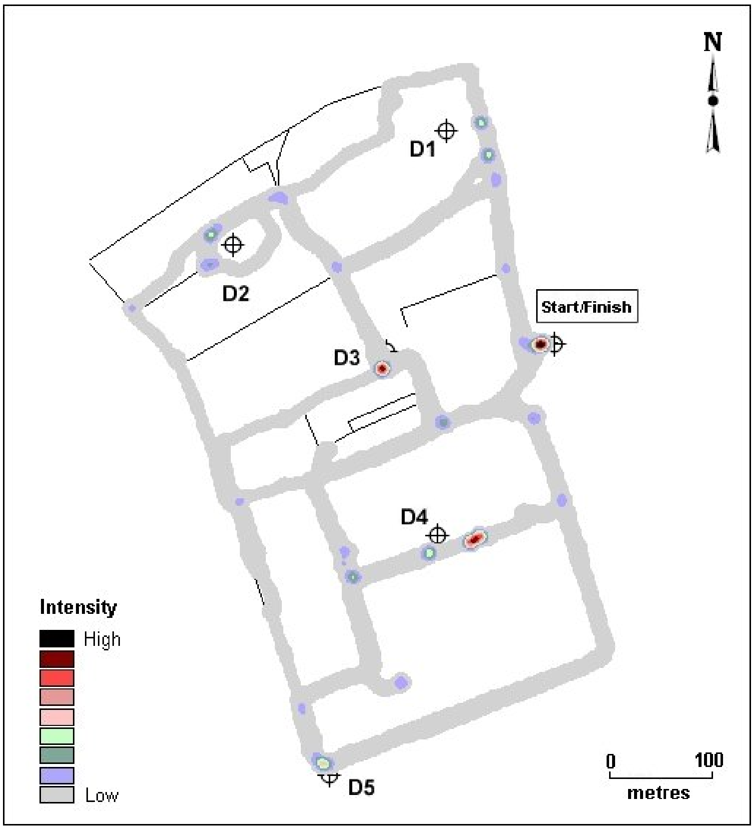
(b)

Figure 8.39 Intensity maps for PDA spatial information usage group IN-G1:

(a) setting U1; (b) setting U2.

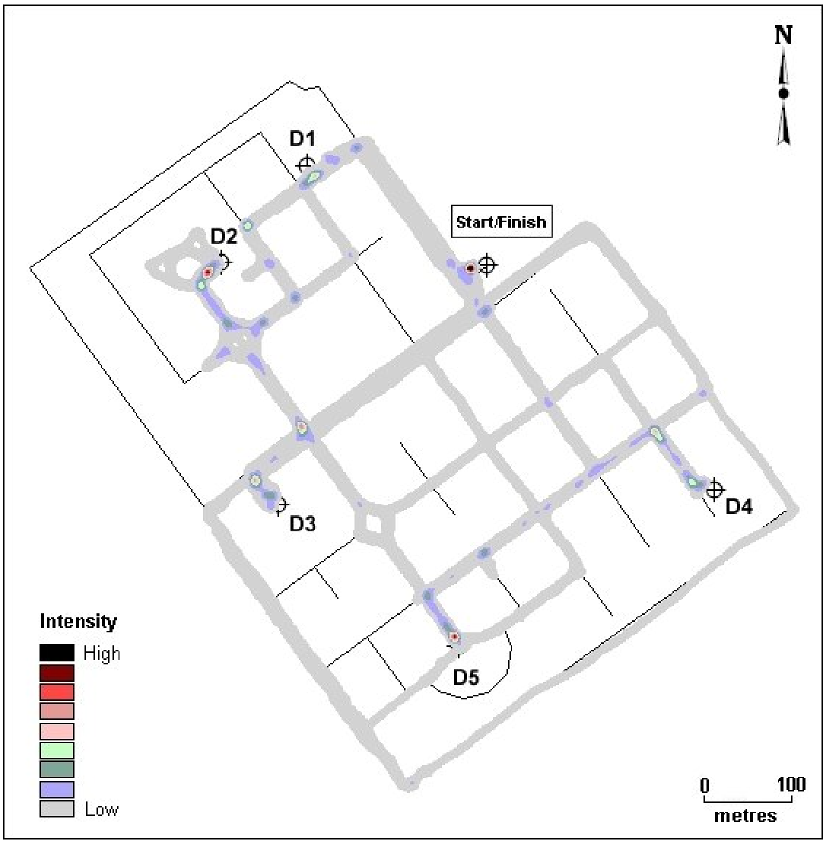


(a)

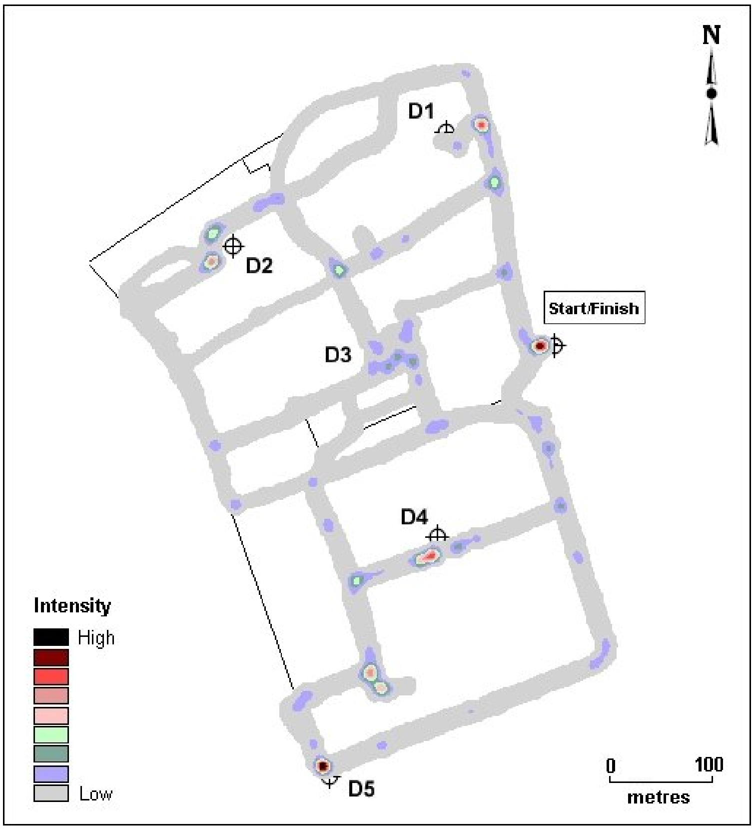


(b)

Figure 8.40 Intensity maps for PDA spatial information usage Group IN-G2: (b) setting U1; (b) setting U2.

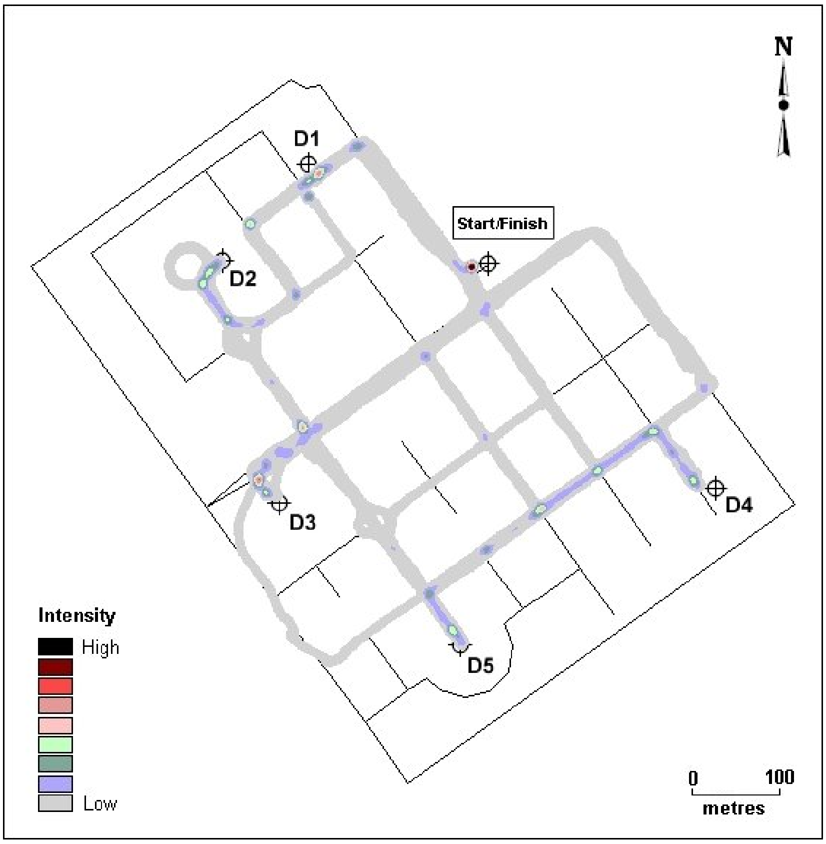


(a)

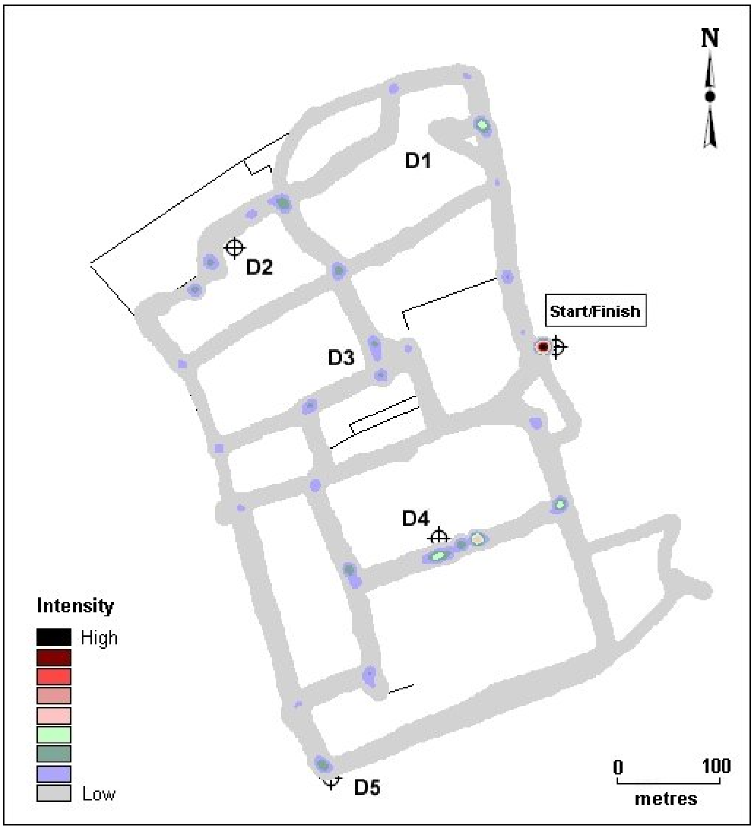


(b)

Figure 8.41 Intensity maps for PDA spatial information usage Group IN-G3:
(c) setting U1; (b) setting U2.



(a)



(b)

Figure 8.42 Intensity maps for PDA spatial information usage Group IN-G4: (d) setting U1; (b) setting U2.

The intensity maps in Figure 8.39 to Figure 8.42 reveal a number of characteristics of these four groups relating to their wayfinding behaviours. Firstly, the patterns show that there is less diversity in the number of routes chosen by the IN-G1 Group of participants during their wayfinding (Figure 8.39(a) and (b)) compared with the participants in other groups. The participants in the IN-G1 Group have preferences for route information; therefore they were more likely to follow the routes described by the route information. This general lack of route diversity amongst the participants could also reflect that the knowledge gained from the route information was not sufficient to enable the participants to choose other routes. The greatest diversity in route choice is amongst the participants in IN-G3 in setting U1 (Figure 8.41(a)), which could have resulted from the mixed mode of information usage. It could either be the situation that the participants had gained more knowledge about the spatial layout by using different types of information, or the participants may have faced some difficulties but got around them by using a richer mix of information. Moreover, amongst the participants in Group IN-G2, IN-G3 and IN-G4, the difference in the diversity of route choices is less obvious in setting U2 (Figure 8.40 (b), Figure 8.41(b) and Figure 8.42(b)) than in setting U1. The participants in these groups all have some degree of map-oriented information usage although with different emphasis either in overview maps or detailed maps. It may also be that setting U2 offers a more restricted choice of rational routes between successive destinations.

Secondly, there are different patterns of hotspots between the four groups. As shown in Figure 8.42 (a) and (b), for IN-G4, the hotspots with the highest intensities are clearly located at the starting point for the whole wayfinding journey. For setting U2, the hotspot at the starting point has an even greater intensity. This implies that the participants with map-oriented usage with preference for overview maps spent more time at the beginning of the whole journey in familiarising themselves and studying the spatial information via the PDA to plan the wayfinding tasks. In contrast, for the participants in IN-G1 (route information oriented usage group), the hotspots are located at some of the starting points and most of the road junctions (Figure 8.39(a) and (b)). In other words, these participants tended not to spend much planning time at the beginning of wayfinding tasks, but access the information more frequently along the routes. This phenomenon can be observed in both settings U1 and U2. This may result from the nature of the route information which provides successive instructions along the route. Participants may well find it difficult to remember the whole route information, but are likely to access the information incrementally along the routes. However the participants in this group might need more information when they encounter challenging routes such as from D4 to D5 (in setting U2) along which is a cul-de-sac where many participants became lost or confused. For the participants in IN-G2 (Figure 8.40(a) and (b)), most of the hotspots are concentrated at the starting points of each wayfinding task. The intensity of such hotspots is noticeably higher at the starting points of each wayfinding task in U2, although this pattern of hotspots is similar in both settings. Such a pattern implies that the participants studied the spatial information more intensively in planning each coming wayfinding task. This is consistent with the results shown in Figure 8.38. The distributions of the hotpots in Figure 8.41(a) and (b) show that the concentration of hotspots are at the starting points and at locations having a more challenging spatial layout (e.g. the cul-de-sac on the route form D4 to D5 in setting U2, the roundabout on the route from D2 to D3 in setting U1).

The frequency of being lost or confused was also studied in relation to these PDA spatial information usage groups. For the four groups, a Kruskal-Wallis test shows that there is no significant difference with respect to these frequencies. This may be because of the small sample size in each group. Nevertheless, it can be seen from the boxplots (Figure 8.43) that the median frequency of being lost or confused is consistently higher in U2 amongst all groups compared with U1. The effect of setting appears to have had more influence on the participants in IN-G1 Group (Figure 8.43), with setting U2 having the greatest interquartile range in the frequency of being lost and confused.

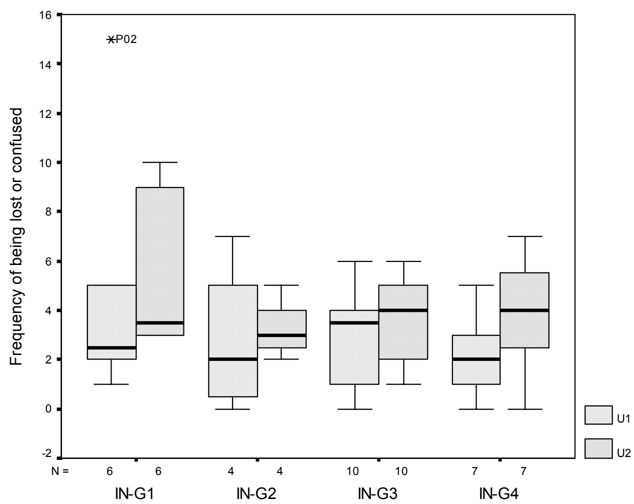


Fig 8.43 Frequency of being lost or confused for four IN groups in settings U1 and U2

Discussion: For the three spatial ability groups SA-G1 to SA-G3, the hotspots for SA-G3 are most concentrated at the starting point of the whole wayfinding journeys and early parts of the wayfinding tasks whilst the other two groups have a more even spread of high intensity locations at different start points for each task, road junctions and some more challenging locations. This phenomenon may reflect that the participants in SA-G3 (self-assessed high score in spatial ability) are more likely to familiarise themselves and study the spatial information from the PDA at the early stage of wayfinding and seem to benefit from developing their spatial knowledge of the layout at an early stage. Furthermore, the participants in SA-G3 seem to have exercised more diversity in their route choices which might have resulted from gaining good spatial knowledge at the beginning of the whole journey. The participants in SA-G1 are less likely to spend more time at the beginning of tasks for information but access information more frequently along the routes taken. For Group SA-G2, the participants appear to spend time studying the information for task planning and access information wherever difficulties occur. Moreover, the spatial layout does appear to have more of an influence on the wayfinding behaviour amongst the participants in SA-G1 and SA-G2.

For different PDA information usage groups, which represent the different preferences in using spatial information wayfinding, there are observable differences in the patterns of wayfinding. The participants with route information oriented usage (IN-G1) tend to take less time for studying the information in planning the task, but access information more intensively along the routes. In contrast, the participants with overview map oriented usage (IN-G4) spent more time studying information at the beginning of the whole journey and have gained more knowledge about the layout and acquire less information during the routes. Another map oriented group, IN-G2, with preferences in detailed maps also spent more time planning but this was concentrated at the starting points of each wayfinding task. The mixed mode information usage group (IN-G3) tends to need information at both starting points of wayfinding tasks and at some decision points such as road junctions. Furthermore, complex settings and locations with more challenging spatial layouts tend to have more an effect on the participants in IN-G1 and in IN-G3.

The planning time is an important and measurable aspect of wayfinding behaviour and information usage. Whilst the boxplots in Figure 8.38 show differences between groups, the intensity maps have shed light on differences in the spatial locations at which planning activities take place.

The group case studies have provided further insights into the relationships between different individuals, their wayfinding behaviours and the ways in which spatial information was acquired. The design of LBS wayfinding applications will thus need to consider individual spatial ability and information preferences. Furthermore there are implications as to where and in what situations more precise and detailed information will be required by these different groups.

8.7.2 Case studies: individual level

This part of the case study analysis focuses on individual participants selected from different self-assessed spatial ability groups (SA groups) and PDA spatial information usage groups (IN groups). The emphasis is on their strategies in using spatial information via the PDA during their wayfinding activities. To begin with, an overview of all 27 participants with their SA-grouping and IN-grouping is given in Table 8.28. In these case studies, there will be reference made to the number of times these participants were lost or confused, so also listed in Table 8.28 is the frequency with which participants were lost or confused during their wayfinding tasks in settings U1 and U2. For the aggregated 27 participants, Figure 8.44 shows that participants are more likely to be lost or confused in setting U2 than in setting U1, a Mann-Whitney U test: U(27,27) = 248.5 p = 0.043 confirming the significant difference. This again indicates that setting U2 is more challenging that U1.

PID	*SA-group*	*IN-group*	Setting U1	Setting U2
P02	3	1	15	10
P03	3	4	2	3
P04	3	2	3	3
P05	1	1	2	3
P06	1	4	0	0
P07	2	2	1	2
P08	1	4	1	5
P09	3	3	2	2
P11	3	2	7	3
P12	3	4	2	2
P13	2	3	5	6
P14	3	4	5	7
P15	3	3	1	2
P16	2	1	5	3
P17	1	1	2	9
P18	1	3	0	5
P19	1	4	1	6
P20	3	3	4	1
P21	2	3	4	5
P22	1	1	1	4
P23	2	3	6	4
P24	3	3	1	5
P25	2	3	3	4
P26	3	2	0	5
P27	2	3	4	4
P29	3	1	3	3
P30	3	4	4	4

Table 8.28 Frequency of being lost and confused for all participants in both settings

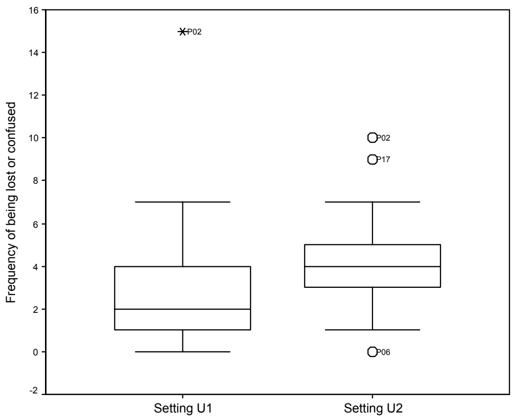


Figure 8.44 Boxplot of the frequency in both settings

For the eight participants selected for this Section, there are two participants in each of the four IN groups. The two participants in each of four IN groups are not from the same SA groups. All SA groups are represented. Listed in Table 8.29 are the eight participants with a number of variables describing their wayfinding characteristics. The variables shown in the table are: participant id (PID); self-assessed spatial ability group (SA group); PDA spatial information group (IN group); frequency of being lost or confused (*Lost/Confused*); the total distance travelled for the wayfinding tasks (*Dtravelled-total*); the time taken for completing the wayfinding tasks ($T_{completion-total}$); frequency of PDA information access ($F_{pda-total}$); the time spent using the information from the PDA ($T_{pda-total}$); the time used for task planning ($T_{plan-total}$).

PID	SA-Group	IN-Group	Lost/Confused		$D_{travelled-total}$		$T_{completion-total}$		$F_{pda-total}$		$T_{pda-total}$		$T_{plan-total}$	
			U1	U2	U1	U2	U1	U2	U1	U2	U1	U2	U1	U2
P05	1	1	2	3	2840.7	2563.3	1319	2548	37	125	197	1161	174	601
P07	2	2	1	2	3268.5	2261.8	1614	1888	48	55	428	808	429	853
P11	3	2	7	3	3535.7	2590.2	2083	1578	73	64	598	523	353	350
P19	1	4	1	6	2966.4	2618.7	1366	1605	43	63	341	473	197	245
P20	3	3	4	1	3780.2	2419.4	1636	1356	25	33	268	330	223	360
P27	2	3	4	4	3242.1	2596.5	1817	1898	63	57	394	497	235	292
P29	3	1	3	3	3161.4	2689.8	1612	1467	41	37	477	467	321	169
P30	3	4	4	4	3109.6	2340.8	1254	1384	54	78	149	409	78	264

Table 8.29 Eight participants studied at the individual level (shaded figures are above median values for all 27 participants).

An information usage track map was created for each of these participants based on the integrated PDA information usage data set with wayfinding position points. The type of spatial information accessed and the location where the PDA was consulted are mapped along the route taken during wayfinding activities. Thus a total of 16 information usage track maps were created for the 8 participants, one for each of the two settings. These are shown in Figures 8.45 to 8.52. Also illustrated in Figures 8.45 to 8.52 are the sketch maps that the participants drew as a part of the post-experiment questionnaires immediately after each set of wayfinding tasks. Each of these sketch maps is displayed under the corresponding wayfinding track completed by that participant. To recap a design element of the experiments (§ 6.4), the last task in each setting (the return from D5 back to the car park from whence they had started) had no route assistance available through the PDA. This was to ensure that all participants were only able to access map information for this final task. To recap: 'route information' refers to the information which provides procedural information such as a route description; 'overview map' refers to the general layout map of the area with landmarks/road names which can be shown by clicking on the map; and 'detailed map' refers to zoomed in maps showing a restricted part of the area but can be scrolled and resembles traditional paper maps in its content and symbology.

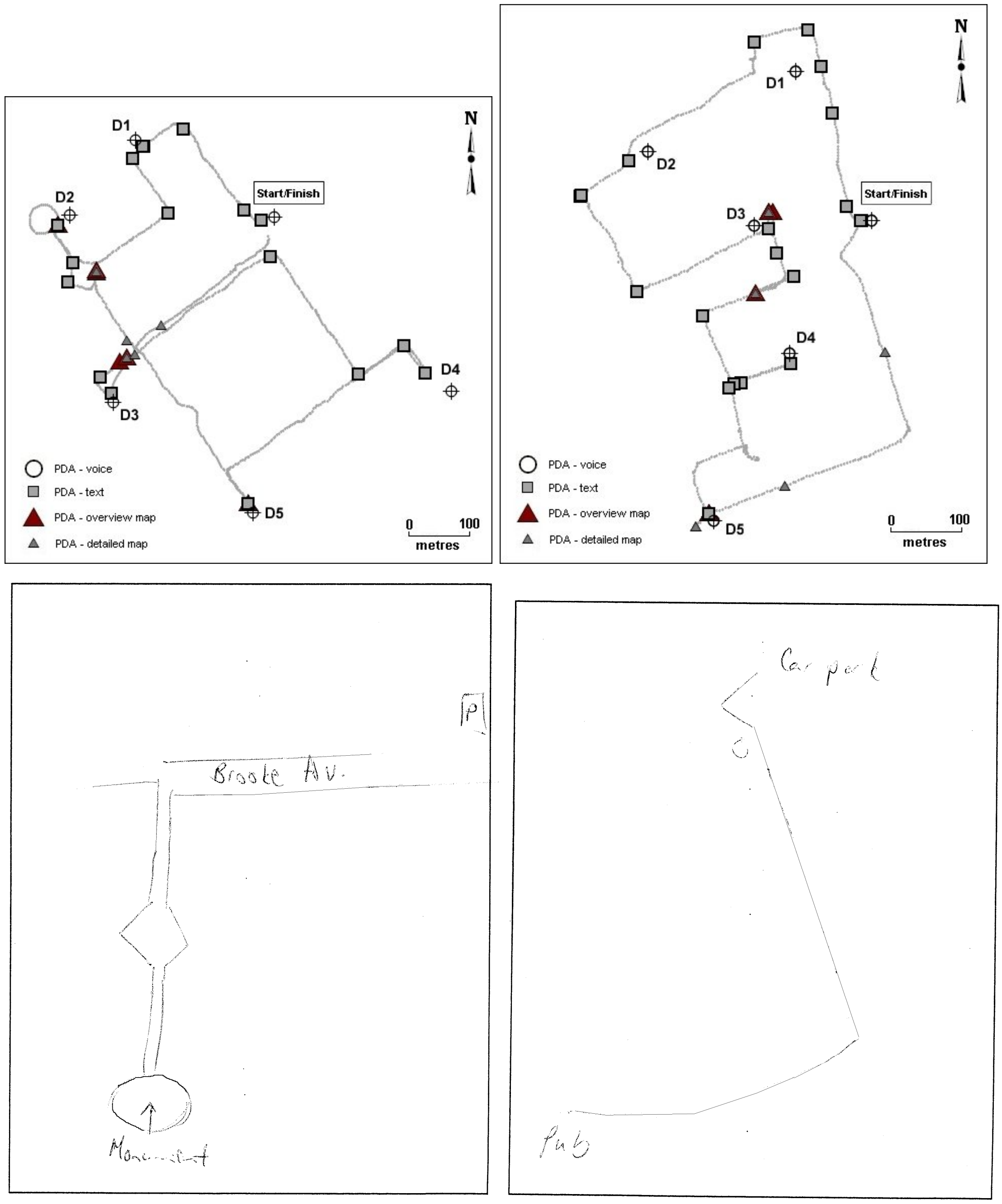


Figure 8.45 Participant P29 (IN-G1, SA-G3): (a) information track map – setting U1; (b) information track map – setting U2; (c) sketch map – setting U1; (d) sketch map – setting U2.

Participant P29. This participant (Figure 8.45) is from Group IN-G1, which is the route information orientated usage group, and is also classified as part of the SA-G3 Group with high self-assessed spatial ability. For the wayfinding tasks completed in setting U1, the distance traveled by this participant is below the median (Table 8.29) with an above median value on the time taken for completion. Regarding the PDA information usage, this participant has below median frequency of information access, but the time spent for using the information accessed via the PDA is above median. The total planning time is also above median. Shown in Figure 8.45(a), a noticeable preference for route information usage can be observed. However, this route dominated information pattern started to change when the participant perceived that the coming tasks were more complex. For example at D2 and D3 is setting U1, a switching between route information and map information is evident. The overview maps and detailed maps were both used to assist in understanding the routes to be taken. Another situation where this strategy was used is where the participant encountered challenging situations (e.g. the roundabout along the route between D2 to D3 in setting U1), where both overview map and detailed map were brought into use. The route information was resumed as the main source once the maps had been used. A similar strategy in spatial information access and usage is observable in setting U2. Route information dominates the PDA usage but at D3 overview and detailed maps were accessed and used for assisting the planning the next task to D4. After resuming the use of route information, a further challenge arose partway between D3 and D4 necessitating the use again of overview maps and detailed maps. When the route information was not available through the PDA on the last leg, overview maps and detailed map were again used. For setting U2, the $T_{pda\text{-}total}$ for this participant is higher than median but the $F_{pda\text{-}total}$ is lower than the median value, mirroring performance in setting U1. This implies that the participant was more likely to spend time to consult the information accessed on the PDA than to just glance at it. The participant became lost or confused three times each in settings U1 and U2. Both of the sketch maps drawn by this participant exhibit similar characteristics in that they are simple and only the last leg of the journey was recorded. The sketch map for U1 has the main landmarks whilst sketch map for U2 has the correct orientation but only the starting point and destination shown. This might reflect the fact that this individual had low comprehension of the whole spatial layout of the setting, but had nevertheless developed a degree of spatial knowledge with help from the PDA sufficient for the wayfinding tasks.

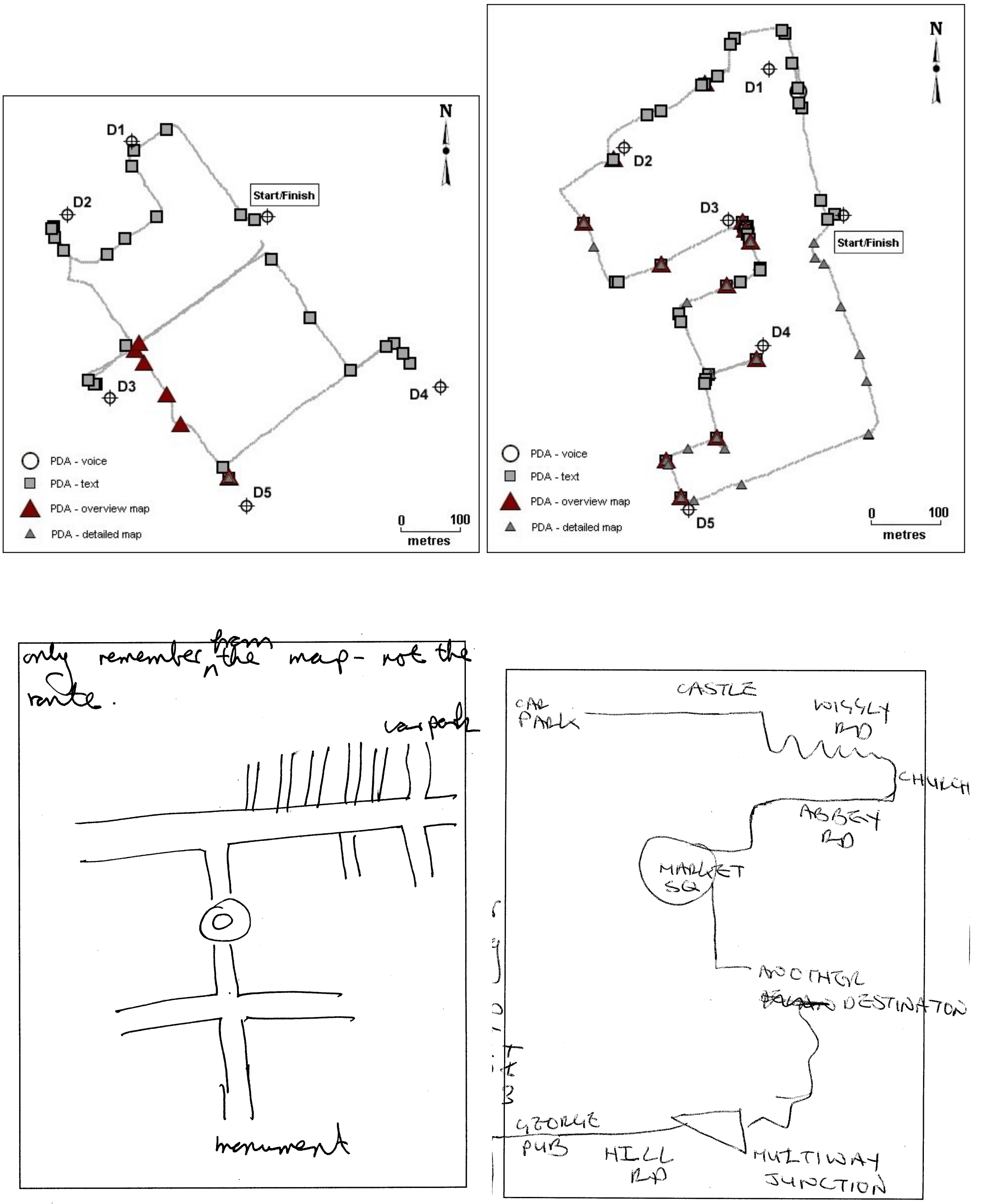


Figure 8.46 Participant P05 (IN-G1, SA-G1): (a) information track map – setting U1; (b) information track map – setting U2; (c) sketch map – setting U1; (d) sketch map – setting U2.

Participant P05. This participant (Figure 8.46) is also from the IN-G1 Group (route information orientated usage group), but belongs to Group SA-G1 with low self-assessed spatial ability. This participant has below median values for variables $D_{travelled}$, $T_{completion}$, $F_{pda-total}$, $T_{pda-total}$, $T_{plan-total}$ for the wayfinding tasks completed in setting U1, but with all these variables at above median values in setting U2 (Table 8.29). Thus setting U2 appears to have been particularly challenging for this participant, more so than for many other participants. From the information usage track map for setting U1 (Figure 8.46(a)), there is clear preference for route information usage concentrated in areas around the starting points of each wayfinding task and decision points such as road junctions. Only on the last leg of the whole wayfinding journey was map information used, primarily because the route information was not available from the PDA. The overview maps with detailed maps were used at the starting point of the last leg whilst the overview maps were frequently consulted during the first half of the final leg. In setting U2, a clearer strategy emerges in the pattern of the information access and usage. Route information is used until a challenging situation is encountered whereupon overview and detailed maps are used to resolve it. This is not dissimilar to participant P29 discussed above but with more intensive use of the PDA. Again, on the final leg of the journey, the detailed map is used frequently as no route instructions are available. For the sketch map for setting U1, again only the last lag of the whole journey is recorded. As noted in the participant's written comments, this is only 'remembered' because of the enforced map use on the last leg. The sketch map for setting U2 has many of the correct features, including the destinations. The route shown, however, is linear and deficient in spatial configuration and is directionally a mirror image of the real world setting. This suggests that the knowledge gained from the route information has not contributed to this participant's knowledge of the spatial layout. However, it is interesting to note that route information in a more regular grid layout did not help the participant to create a linear route map.

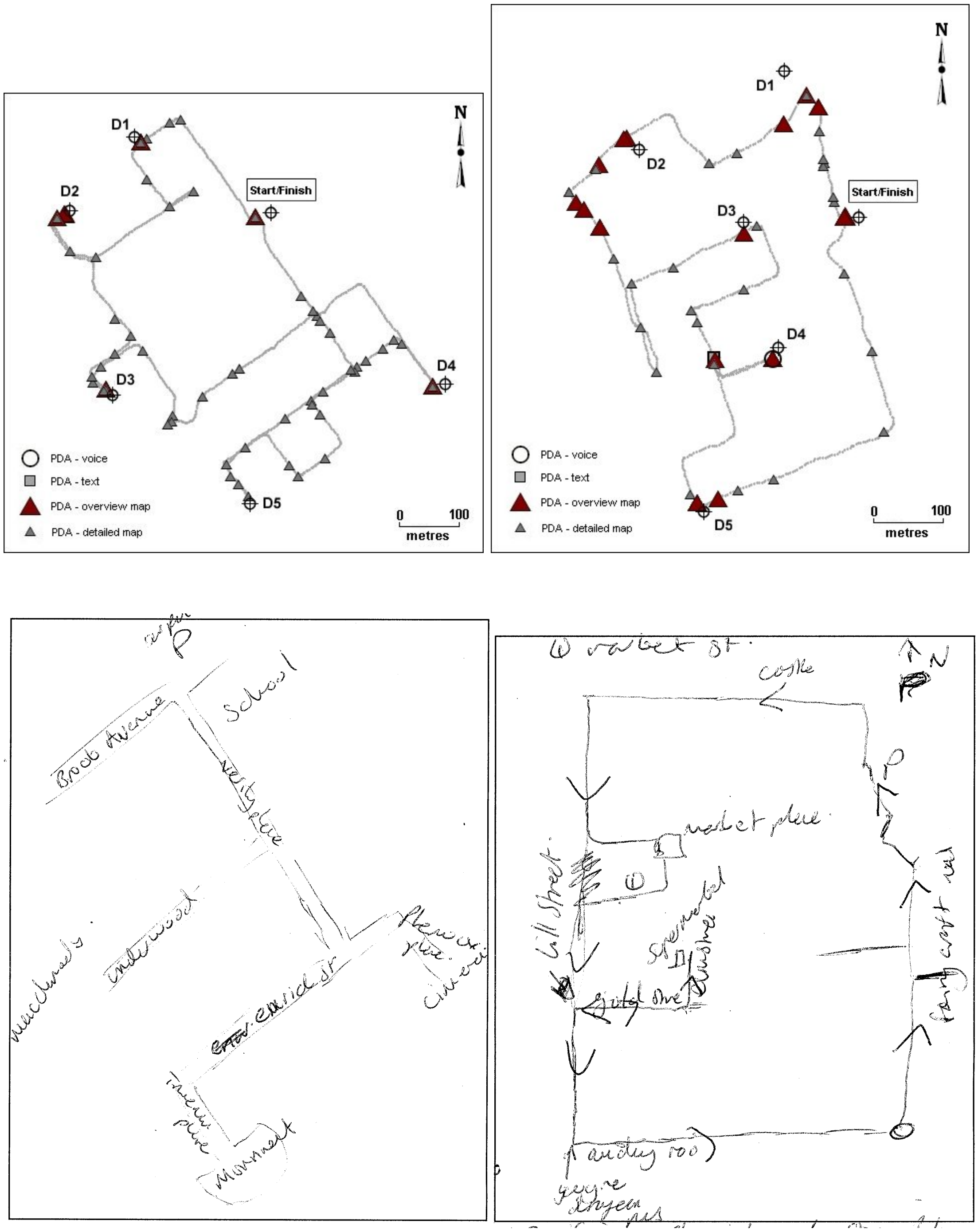


Figure 47 Participant P11 (IN-G2, SA-G3): (a) information track map – setting U1; (b) information track map – setting U2; (c) sketch map – setting U1; (d) sketch map – setting U2.

Participant P11. This participant (Figure 8.47) is from Group IN-G2, which is map oriented usage group with a preference for detailed maps. This participant also belongs to Group SA-G3 with high self-assessed spatial ability. The value of variables $D_{travelled}$, $T_{completion}$, $F_{pda\text{-}total}$, $T_{pda\text{-}total}$, $T_{plan\text{-}total}$ are all above the respective medians. As shown in Figure 8.47(a), in setting U1, there is a clear preference for the use of the detailed map. The use of the overview map is restricted to the starting point of each of the wayfinding tasks whereupon this participant returns back to consult the detailed maps along the routes. This would indicate that overview maps are used to gain knowledge on the configuration of the area when planning the wayfinding tasks and route choices. It also suggests that the detailed maps (showing only part of the whole area, though they can be scrolled) do not provide participants with sufficient knowledge of the entire spatial layout. On the last leg of the journey only the detailed map is used. In setting U2 (Figure 8.47(b)), this participant uses a similar strategy. Again, all the variables are above median apart from $T_{completion}$ which is below the median. Use of detailed maps predominates with overview maps used at the starting points of each wayfinding task. The overview maps were also used at locations where this participant encountered some difficulties, such as along the route between D2 to D3. The last leg is consistent with setting U1 in the use of detailed maps. The frequency of getting lost or confused for this participant was: 7 times in setting U1 and 3 times in setting U2. The sketch map for setting U1 (Figure 8.47(c)) has only part of the area with only the last three destinations drawn, but with very detailed local landmarks such as street names, and has the correct orientation. The sketch map for setting U2 (Figure 8.47(d)) has been placed in a north-south direction, has a simplified route layout but is more detailed in some local areas. Again, the use of detailed maps appears not to have contributed as much as might be expected to this participant's knowledge of the spatial layout of the setting. Also, this participant did not manage to sketch the entire route in setting U1 despite its more regular layout.

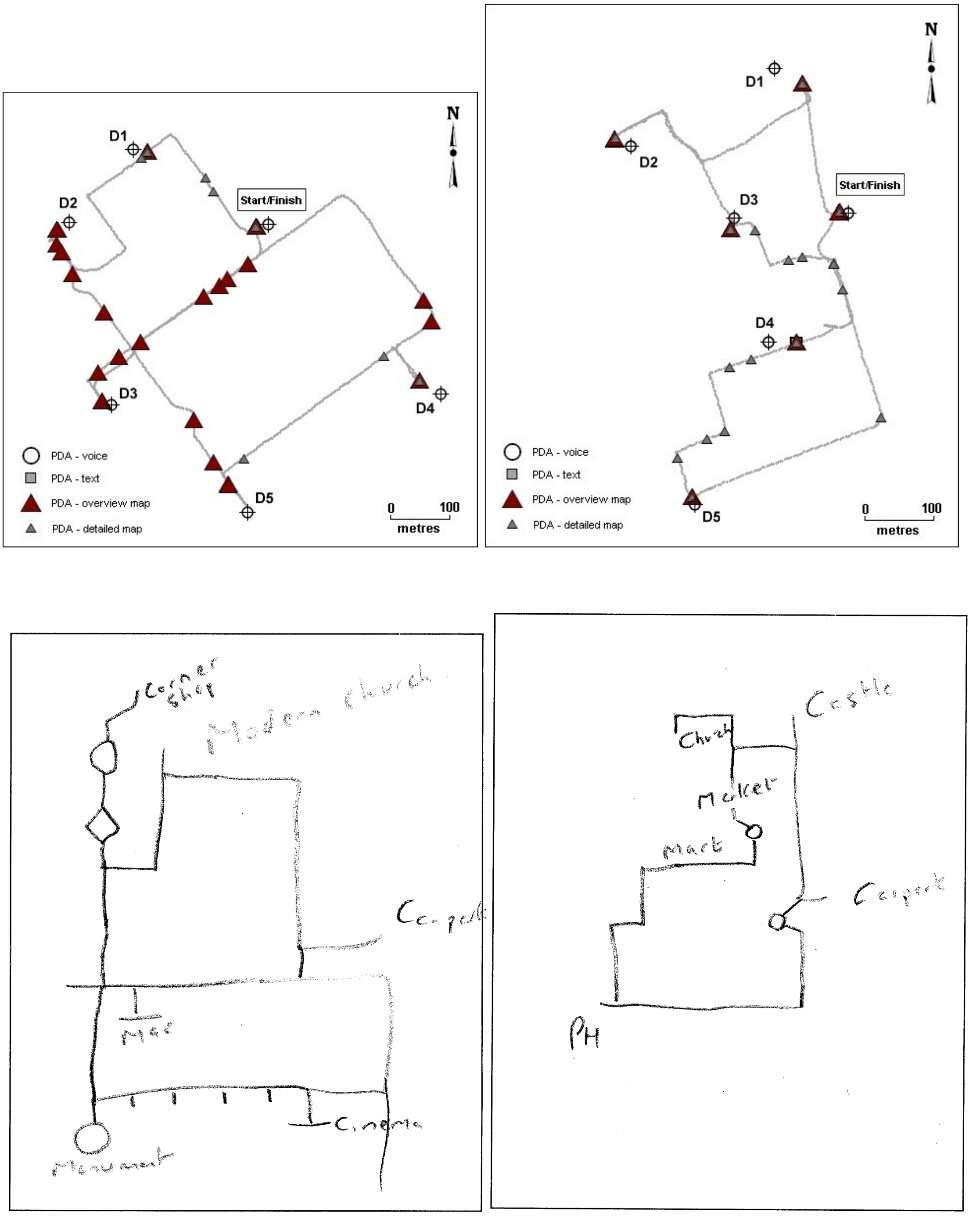


Figure 48 Participant P07 (IN-G2, SA-G2): (a) information track map – setting U1; (b) information track map – setting U2; (c) sketch map – setting U1; (d) sketch map – setting U2.

Participant P07. This participant (Figure 8.48) is also from Group IN-G2, map oriented information usage with preference for detailed maps. This participant also belongs to Group SA-G2 with intermediate self-assessed spatial ability and has higher than median values in all variables $D_{travelled}$, $T_{completion}$, $F_{pda-total}$, $T_{pda-total}$, $T_{plan-total}$ in setting U1. Shown in Figure 8.48(a), this participant began moving in a similar pattern to participant P11 (above), that is, using the overview map at the starting point of the wayfinding task and then using the detailed map afterwards and along the route. However, this strategy changed after D2 where the overview map comes to dominate the type of information accessed and used. Only on the wayfinding task from D4 to D5 does the previous pattern reappear. In setting U2, this participant has values in variables $D_{travelled}$ and $F_{pda-total}$ below the median, with the other values above the median value. Thus detailed map usage appears to take up more time both in time taken for completing wayfinding tasks and the time spent in consulting the PDA for information. Figure 8.48(b) shows a clear pattern in which the overview maps are used at the starting points along with detailed maps, and detailed maps are used along the routes. This implies that the overview maps are used to gain general knowledge of the spatial layout. This is very much like the participant P11 in the same PDA information usage Group IN-G2. The frequencies with which this participant was lost or confused were once is setting U1 and twice in setting U2. The sketch map for setting U1 (Figure 4.48(c)) has been orientated in a north-south direction, but has clear route geometry and destinations marked. The sketch map for setting U2 (Figure 4.48(d)) again is orientated in a north-south direction, but has a more simplified route configuration. The sketch maps also show the approximately correct relative scales of settings U1 and U2.

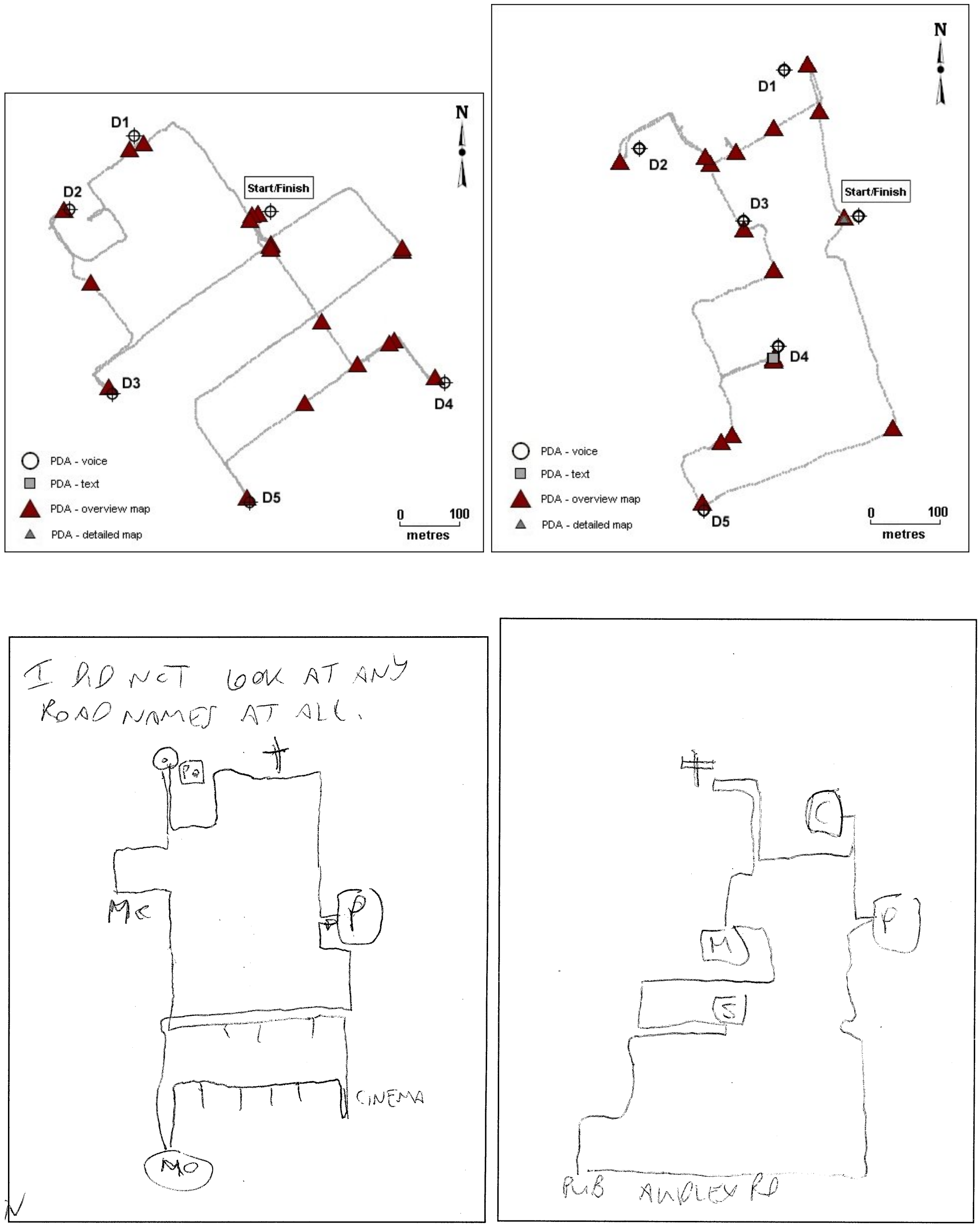


Figure 49 Participant P20 (IN-G3, SA-G3): (a) information track map – setting U1; (b) information track map – setting U2; (c) sketch map – setting U1; (d) sketch map – setting U2.

Participant P20. This participant (Figure 8.49) is from Group IN-G3, which is mix mode of information usage. This participant also belongs to Group SA-G3 with high self-assessed spatial ability. This participant has lower than median values in variables $F_{pda\text{-}total}$, $T_{pda\text{-}total}$, $T_{plan\text{-}total}$ and higher than median value in variables $D_{travelled}$, $T_{completion}$ in setting U1. For setting U2, this participant has lower than median value in variables $D_{travelled}$, $T_{completion}$, $F_{pda\text{-}total}$, $T_{pda\text{-}total}$, $_{\text{-}total}$ and higher than median value in variable $T_{plan\text{-}total}$. The maps shown for settings U1 (Figure 8.49(a)) show that this participant predominantly used overview maps with particularly heavy usage at the starting points of each wayfinding task, and at decision points such as road junctions. For setting U2 (Figure 8.49(b)) again, overview maps dominated the usage. At the beginning of whole wayfinding journey, detailed maps were also used (which might reflect the longer planning time). Route information was also used at D4 in setting U2. The maps and variables show that this participant had lower PDA information usage in general. The participant is also rated highly in self-assessed spatial ability, which may help explain the lower PDA usage in completing the tasks. This participant became lost or confused 4 times in setting U1 and only once in setting U2. The sketch maps given in Figure 8.49 (c) and (d) are consistent, and both have complete routes with all destination. The knowledge of the area seems well developed. For setting U1, no street names were used as landmarks for wayfinding, which is unusual compared to most of the other participants.

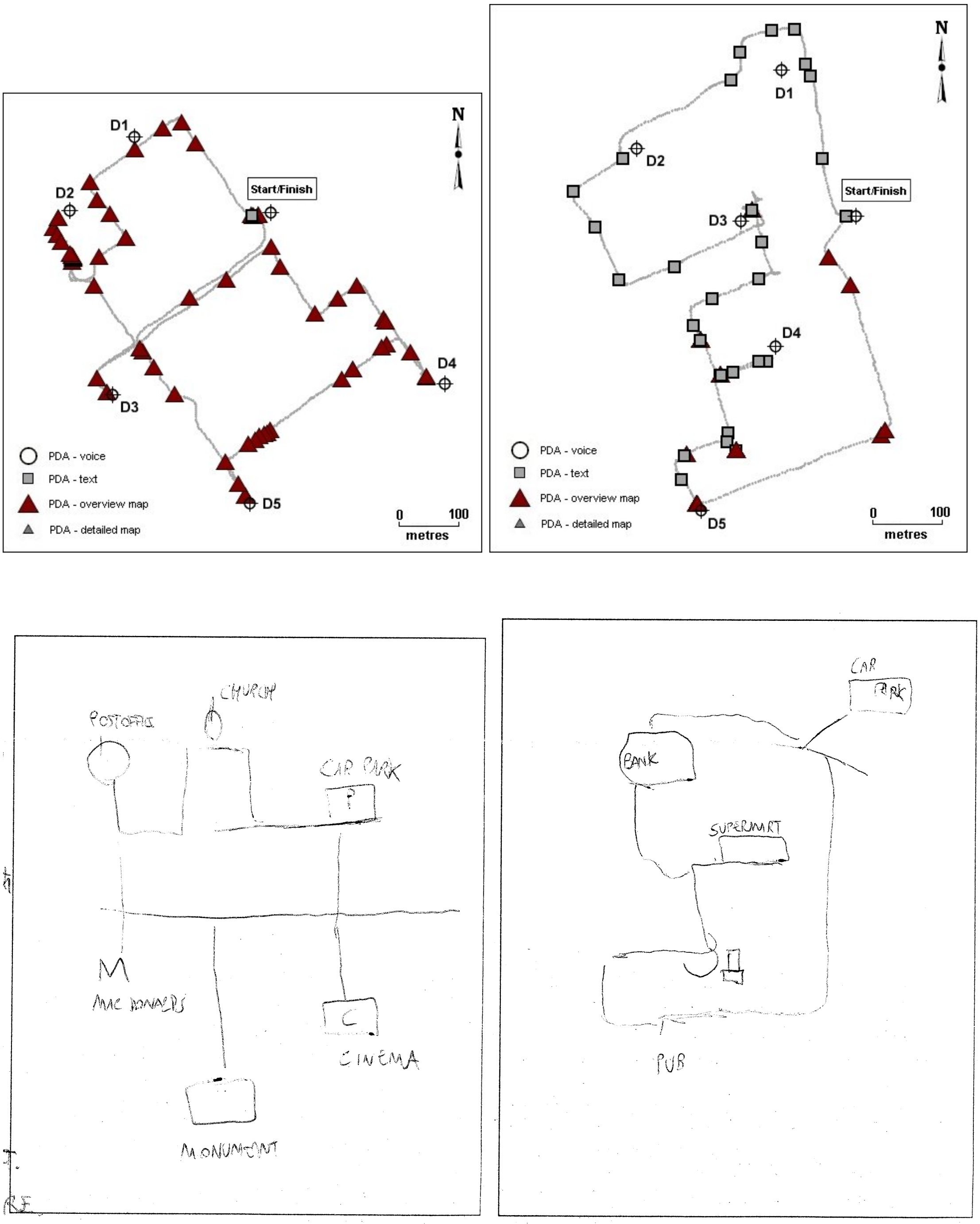


Figure 50 Participant P27 (IN-G3, SA-G2): (a) information track map – setting U1; (b) information track map – setting U2; (c) sketch map – setting U1; (d) sketch map – setting U2.

Participant P27. This participant (Figure 8.50) is also from IN- G3 Group, which is mixed mode of information usage. Furthermore this participant is from Group SA-G2 with intermediate self-assessed spatial ability. This participant has higher than median values in all variables $D_{travelled}$, $T_{completion}$, $F_{pda\text{-}total}$, $T_{pda\text{-}total}$, $T_{plan\text{-}total}$ in setting U1. For setting U2, this participant again has higher than median value in variables $D_{travelled}$, $T_{completion}$, $F_{pda\text{-}total}$, $T_{pda\text{-}total}$ and a lower than median value in variable $T_{plan\text{-}total}$. Thus this participant consistently used more time for completing tasks and for consulting the PDA. In setting U1 (Figure 8.50 (a)), the dominant usage was the overview map, with only a single consultation of the route information at the beginning of whole wayfinding journey. The overview map was then used in order to assist the rest of the wayfinding tasks. However, there is a very high frequency in using the PDA for information along the route. In setting U2 (Figure 8.50(b)), there is a completely different pattern of information usage in that route information was used throughout the first three wayfinding tasks. For the next two wayfinding tasks, overview maps were used at a number of locations where this participant encountered some difficulties. For the last leg, only overview maps were used when the route information was not available from the PDA. The frequency of being lost or confused for this participant was 4 occasions in each setting. The sketch map for setting U1 shown in Figure 8.50(a) has all destinations shown. The sketch map for setting U2 shown in Figure 8.50(b) omits the first two wayfinding tasks, and these happen to be those where route information was exclusively used. This suggests that route information did not appear to help this participant to develop configurational knowledge during these two tasks sufficient for knowledge recall in the sketch map.

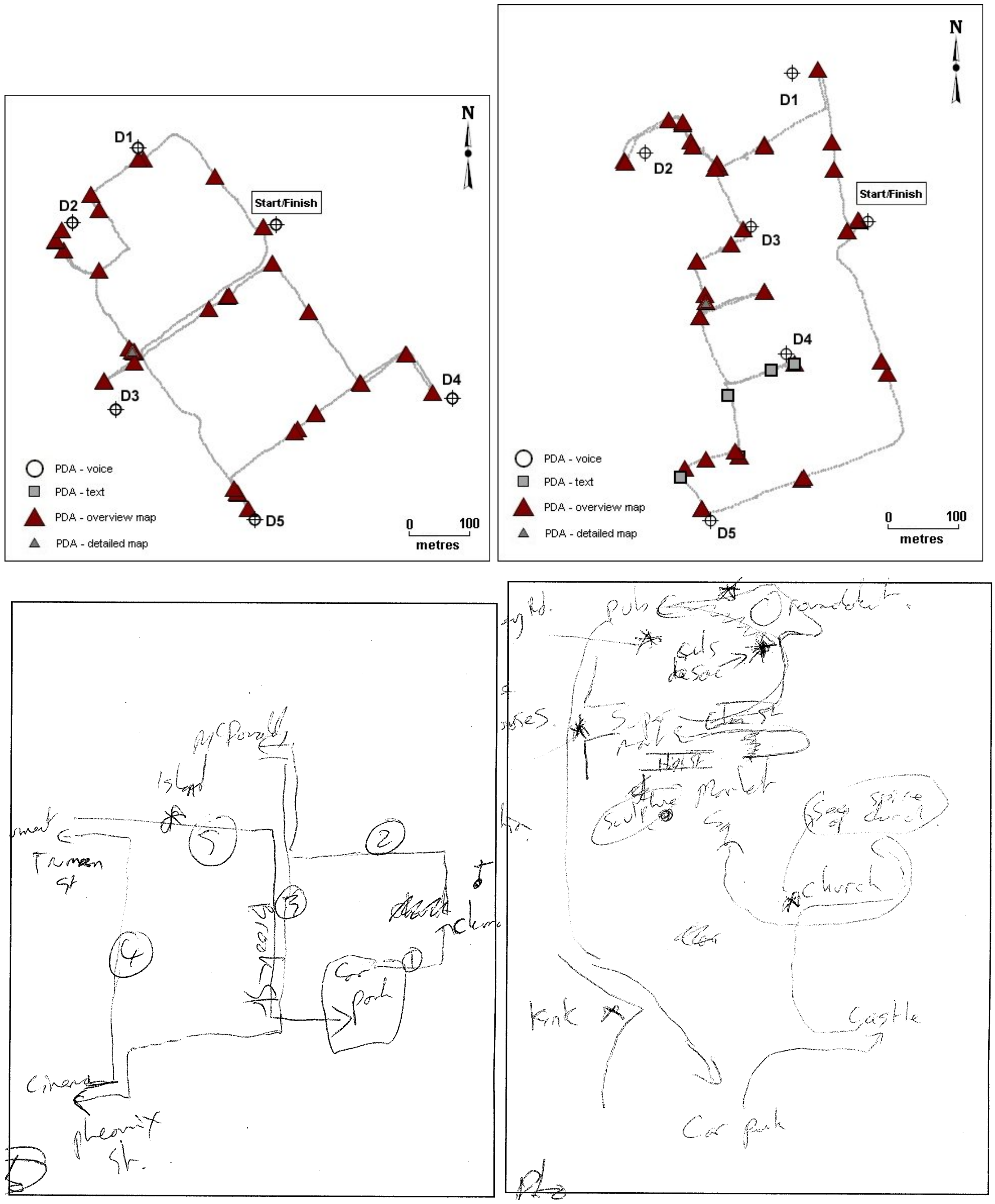


Figure 51 Participant P19 (IN-G4, SA-G1): (a) information track map – setting U1; (b) information track map – setting U2; (c) sketch map – setting U1; (d) sketch map – setting U2.

Participant P19. This participant (Figure 8.51) is in Group IN-G4 which is map oriented information usage with preference for overview maps. This participant is from Group SA-G1 which is low self-assessed spatial ability. This participant has lower than median values in all variables $D_{travelled}$, $T_{completion}$, $F_{pda\text{-}total}$, $T_{pdatotal}$, $T_{plan\text{-}total}$ in setting U1. In contrast, in setting U2 this participant has higher than median value in variables $D_{travelled}$, $T_{completion}$, $F_{pda\text{-}total}$, $T_{pda\text{-}total}$ and lower than median value in variable $T_{plan\text{-}total}$. It appears that the more complex setting made this participant take comparatively longer in all aspects except the planning. For setting U1 (Figure 8.51(a)), this participant used overview maps exclusively with the detailed map used only once, at a road junction. For setting U2 (Figure 8.51(b)), again, use of overview maps dominated. Route information was used, however, for the wayfinding task from D4 to D5, along with overview maps. The frequency with which this participant became lost or confused was once in setting U1, but 6 times in setting U2, again reflecting the differences in complexity between the two settings for this individual.

Both of the sketch maps are rotated 90 degrees clockwise. The sketch map for setting U1 (Figure 8.51(c)) is well structured, shows the route taken and includes most of the destinations (one is missing). The sketch map for setting U2 (Figure 8.51(b)) shows many features including destinations, road features and some annotations. The map is doodle-like in appearance. This and particularly the rotation might reflect the low self-assessed sense of direction characteristic of Group SA-G1.

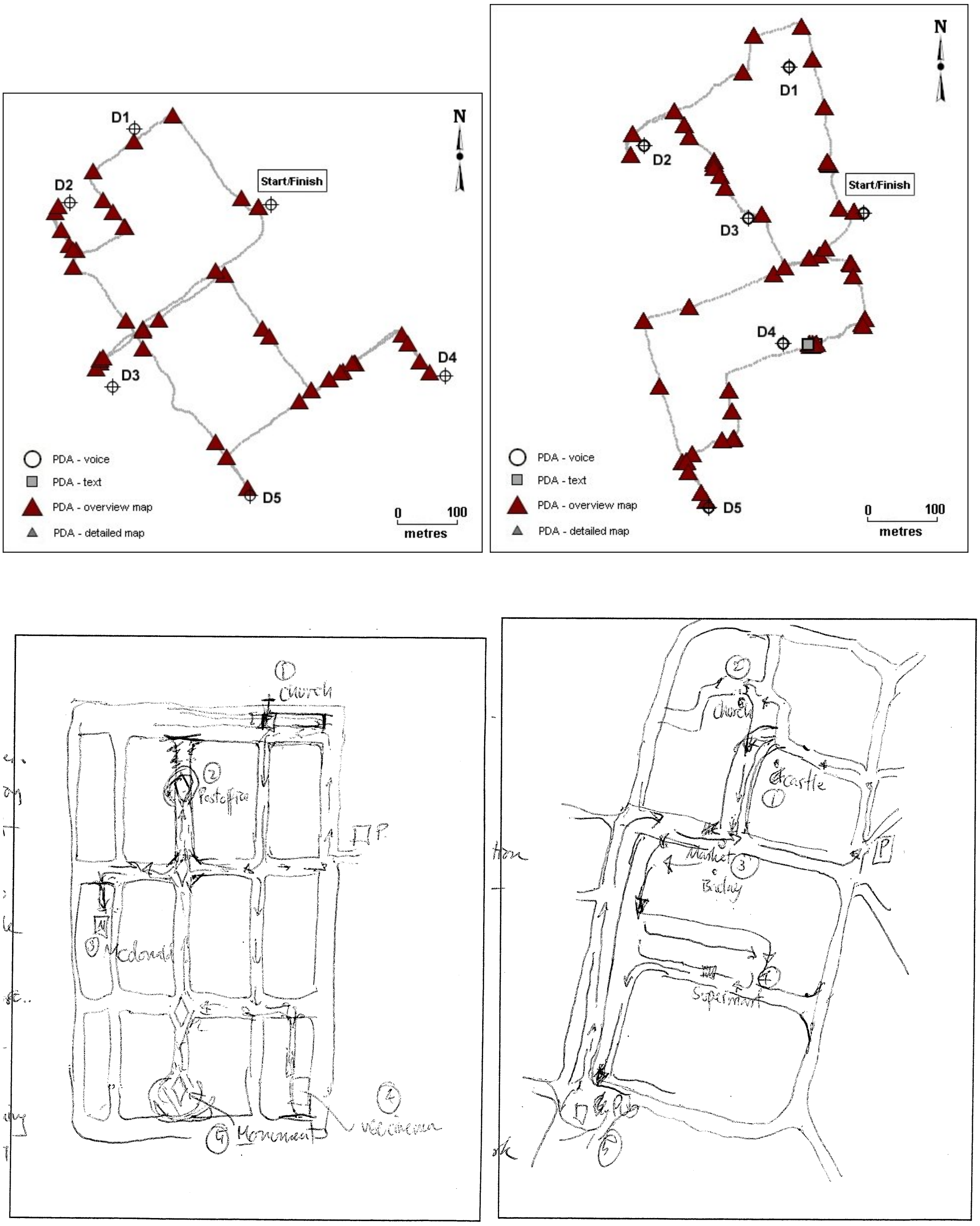


Figure 52 Participant P30 (IN-G4, SA-G3): (a) information track map – setting U1; (b) information track map – setting U2; (c) sketch map – setting U1; (d) sketch map – setting U2.

Participant P30. This participant (Figure 8.52) is also from Group IN-G4, which is map oriented information usage group with preference for overview maps, but from Group SA-G3 with high self-assessed spatial ability. This participant has lower than median values in variables $D_{travelled}$, $T_{completion}$, $T_{pda\text{-}total}$, $T_{plan\text{-}total}$ and higher than median value in the variable $F_{pda\text{-}total}$ in setting U1. For setting U2, this participant has the same pattern with lower than median values in variables $D_{travelled}$, $T_{completion}$, $T_{pda\text{-}total}$, $T_{plan\text{-}total}$ and higher than median value in the variable $F_{pda\text{-}total}$. The frequency of being lost or confused was four times in both settings. Thus the performance between the two settings is very consistent regardless of the contrasting urban morphologies. For both settings U1 and U2, the maps given in Figure 8.52(a) and (b) indicate that overview map usage is almost exclusive. Only once was route information used: at the starting point of wayfinding task D4 to D5 in setting U2. There is a very high frequency of information usage reflected in the variable $F_{pda\text{-}total}$ values. Both sketch maps for setting U1 (Figure 8.52(c)) and U2 (Figure 8.52(b)) are well structured, detailed maps which include roads which were not traveled by this participant. The orientation is slightly askew.

Discussion: This study of individual spatial information usage (via the PDA) in wayfinding and the recall of the experience in sketch maps has provided additional insights not available from the statistical analyses alone. For the four different PDA information usage groups, there appear to be particular strategies that can be identified at the individual level, and could reflect on the characteristics of the groups to which these individuals belong.

For the route information oriented usage, the participants employ overview and detailed maps whenever encountering difficulties or uncertainty either with respect to route choices or decision points. The strategy used is consistent for both settings, although there is a different level of intensity in consulting the PDA between high and low self-assessed spatial ability individuals. The participants from the low self-assessed spatial ability group tended to have high intensity of accessing and using PDA spatial information in the more challenging of the settings (U2). The knowledge of the areas does not appear to include comprehension of their spatial configurations, although this is sufficient for completing the wayfinding tasks.

For the detailed map oriented usage, there is a pattern of using overview maps for planning wayfinding tasks and route choices. The case studies developed here also indicated that these participants do not appear to develop knowledge of the whole area configuration from the information from detailed maps in which the area can only partially be viewed. Again, the difference in spatial ability group does not appear to have the main effect on the strategies of information usages. Moreover, the strategy used is generally consistent between both settings.

For the mixed mode of information usage, there is an alternation in using different types of information amongst the two different settings. It appears that participants choose whatever suites their purpose for the particular environment. This implies that the different settings have an influence on the types of information used for the wayfinding tasks.

For the overview map oriented information usage, the overview maps are used dominantly, with only very few other types of information used occasionally. Again there is consistency in the usage strategy between the two settings and between the two individuals from the different self-assessed spatial ability groups. However, differences arise between the two self-assessed spatial ability groups represented here in respect of the knowledge developed of the areas. This analysis of the individual level strategies is consistent with the group level studies in the previous Section.